TP 14295E

# Risk Study of Double Pilotage in the Laurentian Pilotage Authority Region

*Prepared for:*
Transportation Development Centre
of Transport Canada

*by:*
**MARITIME INNOVATION**

June 2004

TP 14295E

# Risk Study of Double Pilotage in the Laurentian Pilotage Authority Region

*by*
Jacques Paquin and Alain Richard (Innovation Maritime)

*in association with*
Martin Fournier (Robert Hamelin et Associés)
Wayne Rhodes (Rhodes & Associates)

June 2004

This report reflects the views of the authors and not necessarily those of the Transportation Development Centre of Transport Canada.

**Project Team:**

**Jacques Paquin**, Project Leader
**Alain Richard**, Marine Expert
**Martin Fournier**, Risk Assessment Expert
**Wayne Rhodes**, Human Factors Expert

This report is a translation of the original «Étude sur les risques nécessitant le double pilotage dans la région de l'Administration de pilotage des Laurentides», TP 14295F.

105-02659/

Transport Canada Transports Canada

## PUBLICATION DATA FORM

1. Transport Canada Publication No.
TP 14295E

2. Project No.
5446-47

3. Recipient's Catalogue No.

4. Title and Subtitle
Risk Study of Double Pilotage in the Laurentian Pilotage Authority Region

5. Publication Date
June 2004

6. Performing Organization Document No.
T8200-03-3510

7. Author(s)
J. Paquin, A. Richard, M. Fournier and W. Rhodes

8. Transport Canada File No.
2450-CP-13

9. Performing Organization Name and Address

Innovation Maritime
53 Saint-Germain Ouest
Rimouski, Quebec
G5L 4B4

Robert Hamelin et Associés
P.O. Box 95
St. Jean Chrysostome, Quebec
G6Z 2L4

Rhodes & Associates
177 Jenny Wrenway
Toronto, Ontario
M2H 2Z3

10. PWGSC File No.
MTB-3-00700

11. PWGSC or Transport Canada Contract No.
T8200-033510/001/MTB

12. Sponsoring Agency Name and Address
Transportation Development Centre (TDC)
800 René Lévesque Blvd. West
Suite 600
Montreal, Quebec
H3B 1X9

13. Type of Publication and Period Covered
Final

14. Project Officer
André Taschereau

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

16. Abstract

The objective of this study was to answer the following questions:

- What are the second pilot's duties?
- What is the added value of the second pilot?
- When is a second pilot really necessary?
- How much is risk reduced by having the second pilot?

To achieve this objective, an approach was used based on an expanded version of the *Pilotage Risk Management Methodology* (see TP 13741E). The study resulted in a risk analysis model to assess the level of risk for a ship's transit on the St. Lawrence River in regions 1 and 2 of the Laurentian Pilotage Authority.

To illustrate the application of the model in a regulatory context, the report includes tables showing the level of risk generated by a typical vessel transit of various distances and durations. These tables help to asses the relevance of whether a second pilot is required based on the level of tolerable risk.

The study concluded that, in order to achieve optimal management of double pilotage requirements, the level of risk would have to be measured on a case-by-case basis using a further refined and validated version of the model.

17. Key Words
Double pilotage, Laurentian Pilotage Authority, risk, Pilotage Act

18. Distribution Statement
Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication)
Unclassified

20. Security Classification (of this page)
Unclassified

21. Declassification (date)
—

22. No. of Pages
xii, 103 apps

23. Price
Shipping/ Handling

CDT/TDC 79-005
Rev. 96

Canada

Transports Canada Transport Canada

# FORMULE DE DONNÉES POUR PUBLICATION

| | | |
|---|---|---|
| 1. N° de la publication de Transports Canada<br>TP 14295F | 2. N° de l'étude<br>5446-47 | 3. N° de catalogue du destinataire |

4. Titre et sous-titre

Risk Study of Double Pilotage in the Laurentian Pilotage Authority Region

5. Date de la publication

Juin 2004

6. N° de document de l'organisme exécutant

T8200-03-3510

7. Auteur(s)

J. Paquin, A. Richard, M. Fournier et W. Rhodes

8. N° de dossier - Transports Canada

2450-CP-13

9. Nom et adresse de l'organisme exécutant

Innovation Maritime
53, rue Saint-Germain Ouest
Rimouski (Québec)
G5L 4B4

Robert Hamelin et Associés
C.P. 95
Saint-Jean-Chrysostome (Québec)
G6Z 2L4

Rhodes & Associates
177 Jenny Wrenway
Toronto (Ontario)
M2H 2Z3

10. N° de dossier - TPSGC

MTB-3-00700

11. N° de contrat - TPSGC ou Transports Canada

T8200-033510/001/MTB

12. Nom et adresse de l'organisme parrain

Centre de développement des transports (CDT)
800, boul. René-Lévesque Ouest
Bureau 600
Montréal (Québec)
H3B 1X9

13. Genre de publication et période visée

Finale

14. Agent de projet

André Taschereau

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

16. Résumé

L'étude sur les risques nécessitant le double pilotage dans la région de l'Administration de pilotage des Laurentides a comme objectif de répondre aux questionnements suivants :

- Quel est le rôle du deuxième pilote?
- Quelle est sa valeur ajoutée?
- Quand le deuxième pilote est-il vraiment nécessaire?
- Dans quelle mesure le deuxième pilote réduit-il le risque?

Pour atteindre l'objectif de l'étude, une approche conforme à la *Méthode de gestion des risques de pilotage (MGRP)* (voir TP 13741F), a été appliquée et bonifiée. Le résultat de l'étude consiste en un modèle d'évaluation de base permettant d'évaluer le niveau de risque pour un transit sur le fleuve Saint-Laurent dans les circonscriptions de pilotage n$^{os}$ 1 et 2.

Pour illustrer l'application du modèle dans un contexte réglementaire, l'étude comprend des tableaux présentant le niveau de risque engendré par le passage d'un navire-type avec des longueurs et des durées variables. Ces tableaux servent à évaluer la pertinence d'avoir ou non un deuxième pilote à bord en fonction d'un niveau de risque tolérable.

L'étude permet de conclure qu'afin d'arriver à gérer de façon optimale les affectations d'un deuxième pilote lors d'un transit, il serait nécessaire de mesurer le niveau de risque au cas par cas à l'aide d'une version validée et raffinée du modèle.

17. Mots clés

Double pilotage, Administration de pilotage des Laurentides, risque, Loi sur le pilotage

18. Diffusion

Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

| | | | | |
|---|---|---|---|---|
| 19. Classification de sécurité (de cette publication)<br>Non classifiée | 20. Classification de sécurité (de cette page)<br>Non classifiée | 21. Déclassification (date)<br>— | 22. Nombre de pages<br>xii, 103<br>ann | 23. Prix<br>Port et manutention |

CDT/TDC 79-005
Rev. 96

# Executive Summary

Transport Canada mandated Innovation Maritime to carry out a study of the risks requiring double pilotage in the region falling within the responsibility of the Laurentian Pilotage Authority. This mandate arises from the fourth recommendation of the *Ministerial Review of Outstanding Pilotage Issues*, tabled in Parliament in November 1999 by the Canadian Transportation Agency:

> *The Panel recommends that the Laurentian Pilotage Authority be required to carry out a risk-based assessment to determine whether and when requirements for double pilotage are valid, including the current requirement for double pilotage on all vessels during the winter, the requirement for double pilotage on tankers over 40,000 tonnes and the requirement for double pilotage on passenger vessels over 100 metres in length.*

More specifically, Innovation Maritime was to answer the following questions:

- What are the second pilot's duties?
- What is the added value of the second pilot?
- How much is risk reduced by having the second pilot?
- When is a second pilot really necessary?

Accordingly Innovation Maritime developed a methodology that complies with the *Pilotage Risk Management Methodology (PRMM)* (TP 13741E), which was expanded to include human factors analysis using the HEART method. The study began with an evaluation of the needs, issues and concerns (NICs) of the stakeholders, followed by a first round of consultations with these stakeholders. Reconnaissance trips aboard three ships were also made. In addition, a literature review was initiated, which continued as the study proceeded. The review allowed us to define the subject matter and gain a better understanding of the issues. It has four sections: pilotage, accidents/incidents, environmental impact, and human factors.

While the literature review was being performed, a statistical and spatial analysis was conducted using the various available databases so that data relevant to the study could be retrieved from them. The results of the analysis are presented in the report and its appendices.

Scenarios were developed in order to analyse risks and mitigation measures, in accordance with PRMM. These scenarios were the subject of a second round of consultations with stakeholders. Innovation Maritime then developed a risk analysis model, followed by three trips aboard vessels to validate the model and a third round of consultations with stakeholders.

The model is presented in the report and forms the basis of the report's conclusion and recommendations. While the model could be used at the time when a decision is being made about the need for a second pilot, the authors propose using it to create double pilotage tables based on the type and size of vessel, and on the duration and conditions of the trip. An overview of such tables is presented in the recommendations section.

**Recommendation 1: Establish an acceptable risk level**

The model developed for this project demonstrates the feasibility of quantifying the risk associated with ships transiting the St. Lawrence River. The model can also evaluate the contribution of a second pilot to reducing risk. The value of a second pilot depends on the degree of risk we are prepared to accept. In our model, risk is assigned a value between 0 and 30. Based on existing risk levels and conditions for double pilotage, we have identified 0.0048 as the maximum for navigating with a single pilot. Beyond that threshold, a second pilot should be assigned.

**Recommendation 2: Reduce transit duration for District 1**

Our analysis shows that a transit of 11 hours in District 2 has a risk level comparable to a transit of 9 hours in District 1, for ships of the size that normally sail the St. Lawrence River. We recommend keeping the limit of 11 hours for District 2, but reducing the limit for District 1 to 9 hours.

**Recommendation 3: Use length between perpendiculars for ship size**

Contrary to the current regulations, which use deadweight as an indicator of ship size, we believe it is preferable to use the length between perpendiculars, for all types of ship. This parameter has a greater impact on the ship's manoeuvrability and therefore on the risk associated with piloting in confined waters.

**Recommendation 4: Create double pilotage tables**

The maximum risk of 0.0048 together with the maximum transit duration of 9 hours (District 1) or 11 hours (District 2) provide a foundation for rules determining whether a second pilot is required, depending on the size of the ship. We recommend creating double pilotage tables for each of the two districts based on:

1. Three ship types: freighter (other than tanker), tanker, passenger
2. Navigating season: summer or winter (after lighted buoys are removed and after a certain amount of ice has formed)
3. Time of trip: day or night
4. Special condition: with or without docking

Examples of such tables are given in the report for each of the three types of ship sailing at night in summer. The model could be used to create similar tables to cover all the conditions set out above. A total of 72 tables would be needed (3 ship types x 3 seasons x 2 times of day x 2 special conditions x 2 districts).

Recommendation 5: Add other mitigation measures and aggravating factors

Measures other than a second pilot could be considered in order to reduce risk. In this study, we have looked at three:

- bridge resource management;
- crew that has experience navigating the St. Lawrence;
- a good electronic navigating system that complies with standards and includes up-to-date S-57 electronic charts.

Use of one or another of these measures could make it possible to avoid having a second pilot. However, our model would need to be validated before we could recommend changing the regulations in that regard. Also, mechanisms would need to be in place to determine whether such other mitigation measures are in fact present on a ship, and whether they meet whatever requirements may be defined.

Regarding the aggravating factors that may increase risk, the figures presented in the report assume normal navigating conditions, a ship of average manoeuvrability and in good condition, and a typical crew. If these assumptions are not satisfied, the risk level could increase enough to exceed our threshold value. A ship that would normally be exempted according to the figures presented in the report would then be required to have a second pilot.

Incorporating other mitigation measures and aggravating factors would make the use of the tables considerably more cumbersome. It would probably not be worthwhile unless the model is being used on a case-by-case basis. Still, other methods of reducing risk cannot simply be ignored, nor can factors that may increase risk. It must also be borne in mind that while pilotage conditions are always changing, the amendment process for regulations is very slow (the most recent amendments were made a decade ago).

Recommendation 6: Continue to develop the model

It has been shown that our model can objectively establish the level of risk associated with ships navigating the St. Lawrence River. However, if we wish to create tables for all conditions, as discussed in Recommendation 4, then the model will need to be further developed. The process of running thousands of theoretical transits needs to be speeded up, and the analysis of results needs to be optimized. It would also be desirable to develop an interface that facilitates use of the model by users who are not familiar with it.

We have also seen that the model can evaluate the impact of other mitigation measures and of aggravating factors. However, validation work remains to be done if this aspect of the model is to meet needs. Once that work is done, the double pilotage tables would be changed accordingly. This work would also make it possible to explore in greater depth how the model could be used as a tool to determine double pilotage without the need to consult tables.

We therefore recommend that work on developing the model continue.

## Table of Contents

1. Introduction ........ 1

2. Methodology ........ 7

- 2.1 Identify the issue to be addressed and the nature and scope of the decision to be made ........ 7
- 2.2 Identify the stakeholders and their needs, issues and concerns ........ 8
- 2.3 Identify hazards related to situations requiring double pilotage ........ 8
- 2.4 Develop risk scenarios for identified hazards ........ 10
  - 2.4.1 Preliminary analysis ........ 10
  - 2.4.2 Quantitative method ........ 11
- 2.5 Assign a level of risk to each adverse consequence ........ 13
  - 2.5.1 Fault trees ........ 13
  - 2.5.2 Human Error Assessment and Reduction Technique (HEART) ........ 13
- 2.6 Evaluate current preventive measures and their ability to reduce risk ........ 14
- 2.7 Validate hazards, risk scenarios and preventive measures ........ 14
- 2.8 Identify the best risk control option ........ 15
- 2.9 Prepare an effective implementation plan ........ 15

3. Review of the literature on double pilotage ........ 17

- 3.1 Pilotage ........ 17
- 3.2 Accidents and incidents ........ 18
  - 3.2.1 Accident reports ........ 19
  - 3.2.2 Ship characteristics ........ 20
  - 3.2.3 Navigational aids and channel size ........ 21
  - 3.2.4 External factors ........ 22
- 3.3 Environemntal impact ........ 23
  - 3.3.1 Identification of hazards ........ 23
  - 3.3.2 Identification of types of consequences and types of damage ........ 28
    - 3.3.2.1 Consequences ........ 28
    - 3.3.2.2 Damage ........ 29
- 3.4 Human factors ........ 32

4. Statistical and spatial analyses ........ 33

- 4.1 Pre-processing of data ........ 33
- 4.2 Statistical analysis ........ 33
- 4.3 Spatial analysis ........ 34

5. Development of scenarios ........ 35

- 5.1 Description of risk scenarios ........ 35
- 5.2 Consequences and severity ........ 41

6. Risk analysis model ........ 43

- 6.1 Components of the model ........ 43
  - 6.1.1 Human Error Analysis and Reduction Technique ........ 45
  - 6.1.2 Impact of aggravating factors ........ 47
  - 6.1.3 Sector of navigation ........ 50
- 6.2 Using the model ........ 51

7. Results ... 53
  7.1 Scenario versus transit ... 53
  7.2 Selection of inputs ... 53
    7.2.1 Scenario defining inputs ... 54
    7.2.2 Mitigation measures ... 56
    7.2.3 Aggravating factors ... 56
  7.3 Model outputs ... 57
    7.3.1 Comparison of sectors by transit duration, mitigation measures, and day versus night ... 58
    7.3.2 Comparison of sectors by transit duration and ship length ... 60
    7.3.3 Comparison of sectors by environmental conditions ... 63
    7.3.4 Risk for different ship types ... 65
    7.3.5 Risk related to docking ... 66
    7.3.6 Risk with mitigation measures ... 66
8. Conclusion ... 69
9. Recommendations ... 85
Bibliography ... 95

## List of Appendices

1. Human Factors Literature Review
2. Human Error Analysis Methodology
3. Statistics Report
4. Spatial Analysis Maps
5. Scenarios
6. Manoeuvrability
7. List of Participants Consulted
8. Fault Trees

## List of Tables

Table 1 Conditions and hazards ..... 11

Table 2 Principal factors for assessing pilot-related risks ..... 12

Table 3 Hazards associated with navigating on the St. Lawrence River ..... 25

Table 4 Summary of hazards associated with different sections of the St. Lawrence ..... 27

Table 5 Summary of consequences and associated damage ..... 31

Table 6 Hazards and aggravating factors selected for development of scenarios ..... 37

Table 7 Scenarios ..... 40

Table 8 Calculation of severity of consequences ..... 41

Table 9 Consequences of scenarios and their severity ..... 42

Table 10 Data for calculating probability of occurrence using HEART ..... 46

Table 11 Influence of aggravating factors ..... 49

Table 12 Results by duration for two sectors and daytime navigation ..... 58

Table 13 Results by duration for two sectors and nighttime navigation ..... 59

Table 14 Results for two sectors by duration and ship length ..... 61

Table 15 Results for two sectors by environmental conditions ..... 63

Table 16 Results for two sectors by environmental conditions and transit duration ..... 64

Table 17 Risk analysis for different ship types ..... 65

Table 18 Risk related to docking ..... 66

Table 19 Impact of mitigation measures on risk ..... 67

Table 20 Risks for freighter (other than tanker) at night in summer in District 1, by ship length and transit duration ..... 75

Table 21 Risks for freighter (other than tanker) at night in summer in District 2, by ship length and transit duration ..... 76

Table 22 Risks for passenger ship at night in summer in District 1, by ship length and transit duration ..... 77

Table 23 Risks for passenger ship at night in summer in District 2, by ship length and transit duration ..... 78

Table 24 Risks for tanker at night in summer in District 1, by ship length and transit duration ..... 79

Table 25 Risks for tanker at night in summer in District 2, by ship length and transit duration ..... 80

Table 26 Risks for a 230 m freighter (other than tanker) in District 1, by season and transit duration ..... 82

Table 27 Risks for a 230 m freighter (other than tanker) in District 2, by season and transit duration ..... 82

## List of Figures

Figure 1 Outline of the methodology ..... 7
Figure 2 Risk analysis model ..... 44
Figure 3 Logical structure of the risk analysis model ..... 45
Figure 4 Double pilotage table for freighter (other than tanker) at night in summer in District 1, by ship length and transit duration ..... 87
Figure 5 Double pilotage table for freighter (other than tanker) at night in summer in District 2, by ship length and transit duration ..... 88
Figure 6 Double pilotage table for passenger ship at night in summer in District 1, by ship length and transit duration ..... 89
Figure 7 Double pilotage table for passenger ship at night in summer in District 2, by ship length and transit duration ..... 90
Figure 8 Double pilotage table for tanker) at night in summer in District 1, by ship length and transit duration ..... 91
Figure 9 Double pilotage table for tanker) at night in summer in District 2, by ship length and transit duration ..... 92

# 1. Introduction

The current Laurentian Pilotage Authority Regulations specify that, in Districts 1 and 2, two licensed pilots or holders of pilotage certificates must be on board under certain conditions. The conditions refer to the type of ship, its size, the transit time and the navigation period.

In the mid-1990s, Transport Canada consulted widely in preparation for drafting the *Canada Marine Act*. The Act, adopted in June 1998, addressed the issue of pilotage and resulted in amendments to the *Pilotage Act*. In the aftermath of these changes, Transport Canada also received a mandate to look into certain deferred matters related to pilotage, which appeared in the form of 21 recommendations in a document entitled *Ministerial Review of Outstanding Pilotage Issues*, tabled in Parliament in November 1999 by the Canadian Transportation Agency. The fourth recommendation concerns the problem of determining the circumstances under which two pilots should be required in designated areas of the Laurentian Region:

> *The Panel recommends that the Laurentian Pilotage Authority be required to carry out a risk-based assessment to determine whether and when requirements for double pilotage are valid, including the current requirement for double pilotage on all vessels during the winter, the requirement for double pilotage on tankers over 40,000 tonnes and the requirement for double pilotage on passenger vessels over 100 metres in length.*

This recommendation arises from criticisms and arguments made by associations and groups concerned with shipping on the St. Lawrence. It is also supported by the fact that the Canadian Transportation Agency does not think double pilotage should be imposed indiscriminately. In short, the recommendation is aimed at making a clear determination of the conditions that justify double pilotage.

### Background

Originally, the assignment of a second pilot during the winter navigation period was an unofficial practice. Pilots were in the habit of working in pairs once the navigation aids had been removed from the water. The second pilot received an unofficial payment that was less than what the first pilot received. Then in 1930 the pilots went on strike because the shipowners were refusing to employ a second pilot whom they would have to pay. Because the strike began at the end of the summer season, and the pilots were refusing to work alone, there was a risk of ships being trapped in the ice until the spring if the strike continued. This was unacceptable to the owners, so they decided to accept the practice of having a second paid pilot. According to the Bernier report (1970), the strike lasted only two days.

In 1958 the Shipping Federation of Canada recognized the need for a second pilot during the winter season, but language on double pilotage was not added to the regulations until 1960. Two reasons were given to justify the presence of a second pilot. First, the transit time was longer in winter because of the difficult weather and ice conditions. Second (according to the Bernier report), the second pilot would help the first identify the remaining navigation aids after the lighted buoys had been taken out of the water.

These regulations remained in effect until the Laurentian Pilotage Authority (LPA) was set up in 1972. From 1972 to 1974, during which time the LPA published its first set of regulations, a transitional provision was in effect, according to which a second pilot would be assigned if the transit exceeded 13 hours or if the LPA deemed a second pilot necessary for some other reason. These regulations were amended in 1977 by order-in-council, and ships over 79,999 tonnes were now required to have a second pilot between Les Escoumins and Quebec City.

In 1978 a further amendment required ships over 63,999 tonnes deadweight to have a second pilot between Quebec City and Montreal. In 1980, the limit of 79,999 tonnes was lowered to 74,999 tonnes deadweight between Les Escoumins and Quebec City. A 1989 amendment reduced the maximum hours without a second pilot to 12 consecutive hours between Quebec City and Montreal, and 11 hours between Les Escoumins and Quebec City. The limit of 12 hours for District 1 was reduced to 11 hours in 1990. Finally, on December 7, 1991, the LPA adopted amendments concerning tankers over 40,000 tonnes deadweight and passenger ships over 100 metres in length in both Districts.

Since the first double pilotage regulations, there have been major changes in navigating conditions, in the size and characteristics of vessels, and in navigating equipment. On the one hand, ships perform better and the system of navigational aids is more reliable and effective. On the other hand, transits are now made year-round as far as Montreal with bigger ships that must provide more services in more demanding situations. This is the background to the present study.

Current regulations

The existing regulations on double pilotage read as follows:

35. *(1) The minimum number of licensed pilots or holders of pilotage certificates that shall be on board a ship at any time is one, except that a minimum of two licensed pilots or holders of pilotage certificates shall be on board*

- *a) where the ship is to be piloted in that part of District No. 1 between Montreal and Trois-Rivières or between Trois-Rivières and Quebec and is likely to be under way for more than 11 consecutive hours in that part of that district;*
- *b) where the ship is to be piloted in District No. 2 and is likely to be under way for more than 11 consecutive hours in that district;*
- *c) where a ship in excess of 63,999 tons deadweight is to be piloted in District No. 1;*
- *d) where a ship in excess of 74,999 tons deadweight is to be piloted in District No. 2; or*
- *e) where the ship is to be piloted in District No. 1 or District No. 2 and is*
  - *i) a tanker of 40,000 tonnes deadweight or more, or*
  - *ii) a passenger ship of more than 100 m in length;*
- *f) in District No. 1 and in District No. 2 during the winter navigation period;*
- *g) where, owing to the conditions or nature of the voyage, more than one person is required to perform pilotage duties on the ship; or*
- *h) where the ship is a tug used in towing or pushing one or more barges or scows if any of the barges or scows or the tug is subject to compulsory pilotage.*

*(1.1) Despite paragraph (1)(h), one licensed pilot or holder of a pilotage certificate may be assigned to a tug if*

- *a) the tug is permanently coupled for the duration of the trip at the stern of the barge or scow being pushed in tandem or as a composite unit or with other barges or scows; and*
- *b) the barge or scow does not carry dangerous goods as defined in section 2 of the Transportation of Dangerous Goods Act, 1992 and meets the requirements of Part I of the Oil Pollution Prevention Regulations that relate to construction.*

*(2) For the purposes of paragraph (1)(f), the Authority shall determine the winter navigation period in each pilotage district, in the interests of the safety of navigation, in consultation with the Canadian Coast Guard, pilots who are members of a body corporate as described in subsection 15(2) of the Act, and interested groups of shipowners, on the basis of*

*a) the status of navigational aids;*

*b) weather;*

*c) ice formation and ice conditions; and*

*d) any other pertinent factors.*

*(3) The Authority shall, as soon as practicable after determining the winter navigation period in accordance with subsection (2), inform all affected parties of the determination.*

Sometimes double pilotage is required not by the regulations but by arbitration awards. Thus in District 1, two certified pilots have had to be assigned to certain container ships since April 2000, and two pilots have been assigned to the new generation of 294-metre container ships since June 2003. In District 2, double pilotage has applied since June 2003 to the new 294-metre container ships, though there has been no agreement to this effect between the Corporation of Lower St. Lawrence Pilots and the LPA.

## Objectives of the study

The main objective of this study, as set out in the statement of work in the request for proposals, is to "*carry out a risk-based assessment to determine whether and when requirements for double pilotage are valid in the LPA region, and to determine what the duties of the second pilot and/or pilotage certificate holder should be, if any*". However, the scope of the study is much broader than the existing regulations: it looks at all ships currently subject to pilotage whether by regulation pertaining to double pilotage or otherwise. The study thus goes beyond the framework of Recommendation 4 of the *Ministerial Review of Outstanding Pilotage Issues*. More specifically, it considers the following questions:

- What are the second pilot's duties?
- What is the added value of the second pilot?
- How much is risk reduced by having the second pilot?
- When is a second pilot really necessary?

### Methodological framework: *Pilotage Risk Management Methodology*

The study was to be carried out in accordance with the *Pilotage Risk Management Methodology* (PRMM) (Transport Canada, 2001). This methodology was established as a framework for the risk-based studies that were needed to answer the outstanding questions set out in the *Ministerial Review*. It was devised by the Pilotage Steering Committee, consisting of CEOs from each of the pilotage authorities along with representatives from the Marine Personnel Standards and Pilotage Branch of Transport Canada. PRMM is compliant with the Canadian Standards Association Standard CAN/CSA-850.

### Outline

In the pages that follow, readers will find the results of the work undertaken by Innovation Maritime to answer the questions cited above. Chapter 2 presents the methodology and includes all the stages described in PRMM along with some additional activities that allowed us to better achieve our mandate.

Chapter 3 concerns the literature review. The first part is more general and looks at the literature on various factors directly related to the study, while the second is more specifically concerned with human factors as it relates to pilotage, given the special importance of these factors for risk analysis.

Chapter 4 contains the statistical and spatial analysis. It looks at the results of our analysis of the various databases we consulted, as well as the processing difficulties encountered. It should be noted that the databases were not created in order to meet the needs of risk analysis in relation to pilotage. As a result, we had to combine some of them and do several searches in more than one database. While not exhaustive, our statistical analysis did answer certain questions and contributed to the development of the risk analysis model.

Chapter 5 concerns the development of risk scenarios. The scenarios are crucial, not only with respect to PRMM, but also for the purpose of developing the risk analysis model. The scenarios are described, along with the way in which they were prepared and tested.

Chapter 6 features the risk analysis model. In order to carry out the mandate in an objective manner, we had to create a risk analysis tool that incorporates the scenarios, the aggravating factors and the risk mitigation measures. Our model meets PRMM requirements. While it was only an initial version, and improvements could certainly be made, it was sufficiently developed to guide our work and to draw conclusions and make recommendations.

Chapter 7 presents over the results of applying the model. It gives tables showing the risk related to various conditions, and the contribution of a second pilot to reducing that risk.

Chapter 8 contains the conclusions and recommendations, in which readers will find the answers to the questions we were to address.

The report ends with a bibliography and eight appendices.

# 2. Methodology

The methodology used in this study is based on the Pilotage Risk Management Methodology (PRMM), which Transport Canada required us to use. PRMM involves nine tasks, shown in Figure 1. Innovation Maritime expanded on PRMM on the basis of our thorough knowledge of navigation and an analysis of the role of human factors in pilotage-related risk management. We also drew on multiple sources of statistical information to round out the PRMM process, which is based to a great extent on open communication of information, with feedback and dialogue among interested parties. The result is a risk assessment model for pilotage that forms the foundation for our recommendations. Development of the model is described in greater detail in Chapter 6. This chapter looks at the nine PRMM tasks and the way this methodology was expanded.

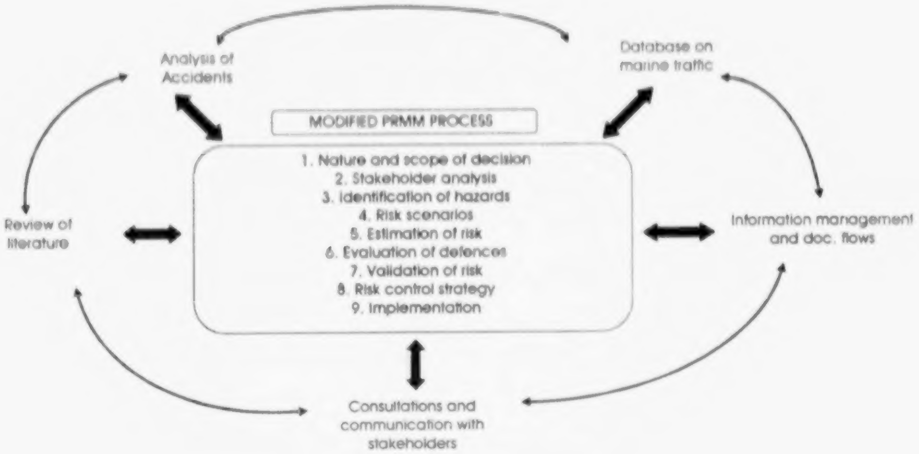

Analysis of Accidents
Database on marine traffic
MODIFIED PRMM PROCESS
1. Nature and scope of decision
2. Stakeholder analysis
3. Identification of hazards
4. Risk scenarios
5. Estimation of risk
6. Evaluation of defences
7. Validation of risk
8. Risk control strategy
9. Implementation
Review of literature
Information management and doc. flows
Consultations and communication with stakeholders

Figure 1 – Outline of the methodology

## 2.1 Identify the issue to be addressed and the nature and scope of the decision to be made

To ensure success in subsequent tasks, the first step was to review all the tasks with the study Steering Committee[1] and look at ways of completing them. During the initial meeting, Committee members and Innovation Maritime reviewed the issue under study, the objectives, the methodology and the timetable. The meeting also identified certain hurdles that might need to be overcome. Reconnaissance trips were added to the work already planned. There was agreement to organize a meeting with the main stakeholder groups in order to present the objectives of the study to them. The Steering Committee asked the consultants to be open to any requests for meetings that might be made by stakeholders.

---

[1] The steering committee comprises representatives from the Laurentian Pilotage Authority, and Transport Canada's Marine Safety Directorate and Transportation Development Centre.

After the meeting, Innovation Maritime prepared a new work plan in response to the concerns that had been raised. This revised work plan was submitted to the Committee for approval.

## 2.2 Identify the stakeholders and their needs, issues and concerns

Stakeholders are defined in PRMM as being any individual, group or organization that could affect, that might be affected by, or that believes it might be affected by a Pilotage Authority decision or activity. Thus the purpose of this second step was to prepare an exhaustive list of stakeholders.

We identified the importance of each stakeholder to the risk assessment process. The needs, issues and concerns (NICs) of each stakeholder were identified through a telephone interview, which led to an individual worksheet showing:

- the impact on that stakeholder of a change in the regulations regarding double pilotage;
- a recommendation (justification) regarding the need to invite that stakeholder to participate.

After the telephone interview, individual and group meetings were held, in particular with pilots' corporations and the Shipping Federation of Canada's Pilotage Committee. Thus stakeholders were grouped in terms of their NIC and then contacted by Innovation Maritime regarding their role in the PRMM consultation process.

A further informational meeting was held with stakeholders on October 29, 2003, at the request of the Steering Committee. Members of the Innovation Maritime project team were introduced, and the mandate and methodology of the study were explained.

## 2.3 Identify hazards related to situations requiring double pilotage

This task involved establishing a list and description of hazardous situations that require double pilotage. To this end, Innovation Maritime conducted a literature review on pilotage, which is described in Chapter 3. In addition, three reconnaissance trips were made, two in October and one in December 2003.[2]

The marine accident reports of the Transportation Safety Board of Canada were used to establish an inventory of accidents and risk factors. The gathering of information on marine accidents was not limited to Canada, however. Innovation Maritime also conducted an international search for reports on marine accidents. This made it possible to enlarge the inventory of risks and consequences, adding concerns that had not yet arisen with respect to the St. Lawrence. Thus every kind of natural, human and technical hazard was identified through a detailed analysis of accidents.

At the same time, Innovation Maritime created a database of navigational incidents/accidents on the St. Lawrence and conducted a study of navigating conditions. Using our access to the Canadian Coast Guard's Data Acquisition and Display System (DADS), we integrated the DADS historical data with the accident/incident data in the MARSIS database of the Transportation Safety Board of Canada. We were thus able to track each voyage and each segment of a voyage during which an incident/accident occurred. Having identified the causes of the accidents, we then analysed the navigating periods and conditions on the St. Lawrence, the ships' operations and the crew qualifications. This made it possible to establish the prevalence of risk in terms of the size, type, age and nationality of the ship, and also in terms of environmental conditions.

During our analysis, we paid special attention to the study of risks related to human factors. We sought a better understanding of mariners' workloads, and in particular the workloads of pilots. We looked at situations on the St. Lawrence where responsibility fell to one pilot, two pilots, a master or officers. While risks associated with the ship or with environmental conditions are important considerations in deciding whether a second pilot or pilotage certificate holder is needed, we felt it was vital to look at the interaction between the human element and the environmental and operational factors that determine safety and economic efficiency. We based our risk analysis and assessment on the duties of the pilot(s) as well as on the duties of the watch officers and helmsmen.

To analyse human factors in relation to all the risks related to double pilotage, it was necessary to perform a thorough evaluation of the conditions that underlie errors. We also looked at types of error and at human capabilities. On the basis of this analysis, we began to develop a risk assessment model based on human factors.

---

[2] One trip was on a passenger vessel between Quebec City and Montreal, the second was on a container ship between Trois-Rivières and Quebec City, and the third, in December, was on a bulker between Les Escoumins and Quebec City (*Regal Princess*, *Canmar Honour*, *Ythan*).

On November 11 and 20, 2003, the first round of consultations was held with stakeholders to obtain their comments on the risk factors that might justify a second pilot. With this information, we were able to clearly pinpoint hazards and risks. The consultations also formed the basis of a working meeting with the Steering Committee.

## 2.4 Develop risk scenarios for identified hazards

This fourth step had three separate but complementary aspects. First, a preliminary analysis identified priorities among the risks identified in the preceding step. Second, risk scenarios were developed for each hazard, using two different methods: fault trees in the case of mechanical and operational failures, and the Human Error Assessment and Reduction Technique (HEART) in the case of human error. Finally, the scenarios were reproduced on the Institut Maritime du Québec's navigation simulator and analysed. Scenario development is discussed in more detail in Chapter 5.

### *2.4.1 Preliminary analysis*

Each of the hazards identified in step 3 was analysed in order to identify priorities. The analysis yielded a qualitative risk assessment for each hazard. The hazards were priorized using frequency/consequence histograms, taking the following into consideration:

- conditions associated with the hazard;
- previous incidents,
- administrative and operational controls;
- consequences of failures of administrative and operational controls, and
- human error.

Each of the conditions that requires double pilotage was associated with one or more adverse outcomes (hazards), yielding a table such as Table 1:

Table 1 – Conditions and hazards

| *Condition* | *Hazard* |
|---|---|
| Strong current | Grounding |
| Heavy marine traffic | Collision |
| Failure of position locating system | Grounding |
| Bad weather | Loss of control of ship |

Table 1 draws on data obtained during step 3 as well as on discussions held with stakeholders in order to draw on their expertise and identify their NICs.

The consequences associated with each of the hazards were classified according to their effect on:

- employee health and safety;
- public health and safety;
- the environment;
- productivity;
- equipment losses;
- financial losses.

Each hazard was then assigned to a frequency class and a consequences class.

### *2.4.2 Quantitative method*

Two complementary methods were used to develop scenarios associated with medium- and high-risk hazards. Fault trees were used to identify a combination of mechanical failures and errors giving rise to hazards, while HEART was used to analyse human errors. At the same time as the scenarios were developed, we also created a model to assess the risk for each accident scenario.

Fault trees

Scenarios were created using available historical data, comments from stakeholders, and the expertise of the Innovation Maritime team. For each medium- or high-risk hazard (identified in the preliminary analysis and validated by the stakeholders), a fault tree was constructed so that the information gathered could be processed in quantitative terms.

In this method, each hazard is broken down into intermediate events, which are in turn broken down, and so on until primary causes are reached. The breakdown uses the logical operators AND and OR to link the events. This graphic method shows a chain of possible events that may lead to a hazard, as well as the interactions among events contributing to an adverse outcome. Fault tree analysis is included in the risk assessment model.

*Human Error Assessment and Reduction Technique (HEART)*

Analysing the human error factor among all the risks related to double pilotage requires a detailed understanding of the conditions that underlie errors, the types of error, and human capabilities. This information is used to develop an error diagram that gives the probability of occurrence of each error that may occur in a given scenario. For this purpose, we used a modified version of HEART along with the weighted impact of the factors listed in Table 2.

Table 2 – Principal factors for assessing pilot-related risks

| *Pilot-related factors:* | *External factors:* |
|---|---|
| 1. Training<br>2. Motivation<br>3. Fatigue<br>4. Experience<br>5. Stress | 1. Local conditions (geography)<br>2. Characteristics and condition of ship<br>3. Weather conditions<br>4. Traffic<br>5. Knowledge and use of English and French by crew members<br>6. Crew qualifications<br>7. Condition of crew (fatigue, etc.)<br>8. Transit plan |

Here are the steps for a HEART analysis:

- Review accident reports to identify scenarios that may involve human error, and the types of error that caused an accident;
- Identify scenarios that are representative of operating conditions and working conditions;
- Analyse the navigational and piloting tasks performed by each pilot or master during the scenarios in order to identify the number of tasks to be performed at once, the equipment and personnel involved, the physical and mental resources required, and the nature of the environment where the activities are carried out;
- Analyse failure modes, effects and potential causes, identifying the errors that may occur in each scenario, the conditions underlying the errors, the consequences and the possible remedies;

- Develop scenarios based on the fault diagram showing the links between the consequences and the probability of occurrence of errors;
- Write a report detailing the main scenarios, the types of errors, the probability of occurrence of errors and the likelihood of critical consequences, with attention to the conditions prevailing at the time of occurrence and a comparison of ships with two pilots (or qualified pilotage certificate holder) versus ships with one pilot.

Our analyses produced information on tasks, failure modes, potential causes, and weightings of the factors in Table 2.

## 2.5 Assign a level of risk to each adverse consequence

A risk level was identified for each of the two methods and for each adverse outcome identified in the preceding steps. A sum of the uncertainties related to the use of historical data available in official statistics was also taken into consideration when creating the analytical model.

### *2.5.1 Fault trees*

Each event identified on a fault tree was assigned a probability so that the probability of the hazard could be calculated. These values were obtained from historical data and from information on equipment, type of ship, etc. Values were also calculated using the risk assessment model.

### *2.5.2 Human Error Assessment and Reduction Technique (HEART)*

Risk assessment was based on ship characteristics (length, tonnage, type, etc.) and trip characteristics, including the navigating conditions. The model was applied, and the model outputs were compared with the statistics on the number and type of accidents, in particular groundings and collisions.

A chart used to program the model gave the basic underlying causes of accidents that are directly related to trip conditions, crew qualifications, operating conditions and ship characteristics.

Finally, the assignment of a level of risk involved consideration of:

- the uncertainty related to the applicability of historical data to current situations, in view of technological changes and new management practices related to equipment and materials;

- the uncertainty related to the incompleteness of the data: since not all risk events are known, historical data underestimate the level of risk.

## 2.6 Evaluate current preventive measures and their ability to reduce risk

Current preventive measures and their ability to reduce risk to an acceptable level are evaluated by comparing stakeholders' NICs with the risk levels identified in the previous step. Understanding preventive measures and their applicability and risk-reduction capacity requires an excellent knowledge of the circumstances for which the measures were established. For this purpose Innovation Maritime drew on the experience and expertise of its own navigation professionals. These professionals identified and evaluated the effectiveness of physical or administrative preventive measures for each risk scenario. To make the analysis easier, each measure was evaluated in accordance with its estimated impact on the frequency and severity of the scenario.

Once each measure and its effectiveness had been determined, a complete list of preventive measures was submitted to stakeholders for validation, during a second round of consultations held on February 17 and 18, 2004. The resulting comments showed whether the preventive measures are effective and feasible. As with the initial consultation, the second round led to the organization of a progress meeting with the Steering Committee.

## 2.7 Validate hazards, risk scenarios and preventive measures

The purpose of this step was to validate the analyses and compare them to the results yielded by the risk analysis model. To this end, observations were made on board three ships transiting in Districts 1 and 2:

1) the oil tanker *Bulduri* travelling from Trois-Rivières to Montreal on March 10, 2004, including the docking manoeuvres;
2) the bulker *Vola No.1* travelling from Montreal to Trois-Rivières on March 11, 2004;
3) the container ship *Conmar Venture* travelling from Les Escoumins to Quebec City on March 12, 2004.

Three separate trips were made because a substantial number of observations were required. An navigation expert and a risk analysis expert were on hand to cover as many points as possible. Afterward, a meeting was held with the Steering Committee.

## 2.8 Identify the best risk control option

This step involved creating a list of feasible risk control options, evaluating them on the basis of stakeholders' NICs and the project's objectives, and recommending an option with respect to double pilotage.

With regard to identifying the feasible options, each physical or administrative preventive measure was evaluated on the basis of its ability to reduce the probability of occurrence or the severity of the consequences arising from a risk. To make the evaluation, Innovation Maritime drew on the expertise of its professionals in the areas of human factors and navigation. These professionals used the risk assessment model that was developed throughout the project.

The impact of the selected options on the stakeholders' NICs was validated during a third round of consultations with stakeholder groups held on March 25 and 26, 2004.

## 2.9 Prepare an effective implementation plan

While preparation of an implementation plan is up to the LPA, Innovation Maritime is responsible for submitting to the Committee the best option with regard to the circumstances under which double pilotage is necessary and for determining the duties of the second pilot. In terms of deliverables, Innovation Maritime submitted this final report containing the answers to these questions to the Transportation Development Centre of Transport Canada.

To conclude, it should be mentioned that throughout the project, members of the Innovation Maritime team met many times and also held telephone conferences almost weekly to follow up on the work and resolve any problems encountered, and in particular to discuss basic issues surrounding double pilotage and the development of the risk assessment model.

# 3. Review of the literature on double pilotage

A major literature review was conducted on the study's four major themes: pilotage, marine accidents, environmental impact and human factors. Sources consulted included specialized studies, government reports, articles by professionals found in specialized publications, submissions by stakeholder groups and arbitration decisions. The literature review was initiated at the outset of the project and continually updated throughout the study.

## 3.1 Pilotage

The basic reference document on pilotage is the *Report of the Royal Commission on Pilotage* (Bernier, 1970). This report provided the foundations for the current pilotage regulations. Of special interest in connection with the present study is the statement in the Report that navigation safety requires the presence of two pilots at the end of the normal shipping season once risks are significantly increased by the arrival of winter, that is, once ice forms and navigation aids are removed from the water; the same is true at the beginning of the season. We also read that if winter arrives late, it is illogical and pointless to assign two pilots as of December 1. Conversely, if winter arrives early and buoys have to be taken out of the water before December 1, it would be inadvisable to refrain from assigning two pilots on the sole grounds that the date fixed by regulation has not yet arrived.

When the Bernier Report was published, the kinds of ships plying the waters of the St. Lawrence were very different from those we see today. They were smaller, the design of the hulls and machinery was different, and the performance of the navigating equipment was quite inferior. Consequently, the problem of double pilotage today is very different from the problem that existed at the time of the Bernier Report. Nevertheless, certain issues considered in the Bernier Report remain relevant and must be periodically re-assessed.

The *Examination of Compulsory Double Pilotage in the Laurentian Pilotage Authority Area* (Dancosse, 1993), provides a thorough analysis of the issue. It shows that the problem arises from the need to find a balance between safety and economic efficiency in piloting operations. It also explains how the issue of double pilotage undermines relationships among stakeholders. In his recommendations, Dancosse writes that "there is room for improvement, and that an imaginative approach will enable the parties to arrive at the appropriate solutions". He concludes by saying that upcoming negotiations "must be approached with a creative and realistic attitude". This makes clear that there is a conflict between two groups of stakeholders. The report recommends maintaining requirements for double pilotage and it takes the view that in case of disputes, the LPA should make decisions in the interest of navigating safety.

Recently the debate over double pilotage has been rekindled as a result of the arrival of very large container ships on the St. Lawrence. These new ships are dealt with in the latest documents on double pilotage in the Laurentian Region, in particular the decision of the arbitration tribunal concerning the vessels *Canmar Pride* and *Canmar Honour* (April 17, 2000). The experts who submitted reports to that tribunal raised a number of valid arguments. However, the decision was based not on their reports, but on the contractual language binding the LPA and the Corporation of Mid St. Lawrence Pilots.

A progress report entitled *Evaluation of the Potential Impact of the New 294-M Container Ships on Navigational Safety and Environmental Protection* (Transport Canada, 2003) analyses the same issue as the arbitration tribunal but for even bigger ships. It looks at technical considerations in order to evaluate the potential impact on safety.

Having examined a large number of documents and reports, we find that there is a conflict between stakeholders as they seek a compromise between safety and economic efficiency in pilotage services. Since the reports tend to promote safety, it is obvious that those stakeholders who want a more economically efficient service feel they are being negatively affected by the decisions, and they are vigorously criticizing the existing regulations.

In our view, the best approach for both groups of stakeholders is an objective risk analysis and a search for mechanisms enabling a fair and efficient distribution of the resources allocated to pilotage. This would seem to be the only approach that could achieve an equitable compromise to satisfy all parties.

## 3.2 Accidents and incidents

The analysis of accidents and incidents described in the available literature was performed according to the type of reference consulted. Both Canadian and foreign accident reports were examined. Particular attention was paid to the sizes and types of ships involved. In addition, documentation on navigation aids and navigable waterways was explored. Finally, a search was made for documents on the factors involved in incidents, such as environmental conditions, crews, ship nationality, inspections, and port state control.

### *3.2.1 Accident reports*

The reports of the Transportation Safety Board of Canada were inventoried and analysed for mentions of the issue of one versus two pilots either in the Laurentian sector or in a similar sector. We also approached the Marine Accident Investigation Branch (UK), the Marine Board of Victoria (Australia) and the Transport Accident Investigation Commission (New Zealand). The investigation reports on what happened when the *Halifax* was stranded (TSB, 1991e) and when the *Irving Nordic* struck bottom near Grondines (TSB, 1991b) were analysed; these incidents were also used in simulations, in order to look at the chain of events and the human factors, and then reproduced in the scenarios.

The recent report on the *Norwegian Sky* (TSB, 1999c) was analysed in detail, as was the report on the *Alcor* (TSB, 1999d) – an occurrence that resembles one of our scenarios. Several other reports also attracted our attention:

- Grounding of the *Transaspiration*; this report is very interesting with respect to the issue of fatigue (TSB, 1993c);
- Near-collision between the *Statendam* and the *Belleise Sound/Radium 622* (TSB, 1996);
- Collision between the *Nirja* and the *Hamilton Energy* (TSB, 1993a);
- Grounding of the *Olympic Mentor* (TSB, 1995a); here the issues were poor vision and fatigue;
- The case of the *Canadian Explorer* (TSB, 1993b), where the pilot fell asleep in the small hours of the morning;
- Collision between the *Cicero* and the *Ziemia Zamojska* (TSB, 1995b);
- Grounding of the *Algolake* (TSB, 1998a), where there were shortcomings with regard to navigation method;
- Grounding of the *Sunny Blossom* (TSB, 1999b), caused by a lack of communication on the bridge;
- Grounding of the *Paterson* (TSB, 1999a), where a single officer was piloting the ship;
- Grounding of the *Enerchem Fusion* (TSB, 1990), where poor communication between master and pilot was reported;
- The *Irving Nordic* case (TSB, 1991b), where the pilot was distracted;
- The collision between the *Canadian Explorer* and the *Lafrenais* (TSB, 1991a), which is of interest concerning communication requirements between ships in confined waters;
- The near collision of the *Irving Canada* and the *Terra Nova* (TSB, 1992), which shows the risk arising from lack of local knowledge.

Analysing these reports gave us a good understanding of the events leading to these accidents, and enabled us to incorporate them in our scenarios.

### *3.2.2 Ship characteristics*

Right from the outset of our statistical analysis, we could see that there was a strong correlation between the causes of marine accidents and the characteristics of the ships involved: the nature of the ship directly affects the level of risk. This observation guided our review of the literature, in that we sought out documents concerning the interaction between the manoeuvrability and the size of ships. Two reports particularly attracted our attention: one by the U.S. Coast Guard Research and Development Center and one by Ship Analytics Inc. for the U.S. Coast Guard and the U.S. Department of Transportation:

- *The Effect of Ship Inherent Controllability on Piloted Performance: Evaluation and Prediction*, CG-D-10-93 (U.S. Coast Guard, 1991)
- *The Effect of Ship Inherent Controllability on Piloted Performance: the Simulator Experiment*, CG-D-10-90 (U.S. Coast Guard, 1990)

These studies, which are concerned with assessing and predicting ship behaviour, clearly show the degree of precision that can be achieved by simulating manoeuvrability. It appears feasible to assess the behaviour of a ship through a rigorous mathematical approach. The studies confirm that the manoeuvrability of a ship can be determined from its characteristics, yielding an indicator of the risk posed by that ship.

We also looked at documentation on simulation and modeling systems, notably from Kongsberg Norcontrol Simulation. The information on ship models and on tests performed on ships made it possible to incorporate ship size and manoeuvrability as factors in our risk assessment model.

Whatever the size and manoeuvrability of a ship, its general condition may also have a major impact on the risk of an accident. We consulted various reports and studies on this matter, notably the annual reports of Transport Canada's Marine Safety Branch on port state control (Transport Canada, 2002), the various publications of the International Maritime Association on port state control, and the publications of the Nautical Institute. As a result, we were able to obtain a picture of the relationships among ship inspection, detention, compliance and flag, and marine accidents. We also used this information to make adjustments to our risk estimation model.

### 3.2.3 *Navigational aids and channel size*

With regard to the physical environment, certain features can be added or improved to facilitate navigation and reduce the level of risk associated with the passage of a ship in a particular area. Navigation aids are a concrete way of assisting navigation under almost all geographical and meteorological conditions. Changing the size of the channel, either in depth or width, can also facilitate the passage of a ship through an area.

We examined the system of navigational aids found in the portions of the St. Lawrence with which we were concerned. The system is operated and maintained by the Canadian Coast Guard. It is a modern and multi-faceted system including electronic aids as well as physical (fixed and floating) aids. These physical aids must be changed on a seasonal basis: the Coast Guard removes lighted buoys for the winter period so that they will not be damaged by ice, and they are replaced by spar buoys that visually indicate the position of the channel during the day, when the water is not covered by ice. The spar buoys can also be detected by radar, but the echo is not nearly as good as that provided by the summer buoys, which are bigger and have radar reflectors. Also, the spar buoys are often submerged under the ice and they do not carry effective luminous or radar-reflective equipment.

When the winter navigating period arrives, the Coast Guard has to remove the navigational aids from the water. This contributes directly to increasing the risk to navigation, thus justifying the use of a second pilot. The report entitled *Risk-based Design Methods for Aids to Navigation in the St. Lawrence River* (Judson et al., 1999) clearly shows the relationship between the level of risk and the physical aids employed.

Since electronic navigational aids are available in the relevant portions of the St. Lawrence River, research was undertaken on radar beacons, differential global positioning systems, electronic navigational charts, AIS, etc. One of the documents consulted was *Rapport sur les essais de systèmes portatifs DGPS sur le Saint-Laurent* (Canadian Coast Guard, 2001).

The documents we consulted gave us a good idea of the importance to risk management of an effective system of navigational aids. Aids were therefore taken into consideration in connection with the risk mitigation measures presented to stakeholders, as well as in connection with aggravating factors. Navigational aids were also taken into consideration in the risk assessment model that was developed.

Like the size of the ship, the size of the channel has a direct impact on the level of risk. *Canadian Waterways National Manoeuvring Guidelines: Channel Design Parameters* (Canadian Coast Guard, 1999) analyses the sections of the St. Lawrence River from Les Escoumins to Quebec City and from Quebec City to Montreal, which both require a special effort from mariners. There are areas where the waterway is not a natural channel but rather an artificial dredged channel of confined size. In the section from Les Escoumins to Quebec City, there is the North Traverse, which has a minimum width of 305 m and a maximum depth of 12.5 m from chart datum. In the section from Quebec City to Montreal, there is a minimum width of 230 m and a depth of 11.3 m. These physical restrictions give rise to effects that are difficult to measure, such as squat, bank effect and so on, which differ from one ship to another. In our analysis on channel size, we consulted the document entitled *Approach Channels: A Guide for Design* (PIANC, 1997).

### *3.2.4 External factors*

In our risk assessment we naturally took into consideration all the factors that can affect ship operation, including currents, winds and ice. To this end, we consulted documents on the measurable effects of these factors. For example we looked at documentation from Norcontrol (limited distribution), and at the Nautical Institute publication *Ship Bridge Simulators*, (Hensen, 1999), which presents mathematical models for estimating the effect of winds on the operation of various ships.

Another important consideration with respect to navigational risk is environmental effects. We therefore looked at such documents as the current atlases put out by the Canadian Hydrographic Service, and the climate maps published by Environment Canada. The different sections of the St. Lawrence River are affected in completely different ways by currents and weather conditions. From Les Escoumins to Trois-Rivières, the currents change direction twice daily, while upstream from Trois-Rivières, the currents can be considered to be constant. Constant currents and a more stable water level reduce the level of risk.

Other external factors are communications jamming as a result of weather conditions and the effects of noise. Fog, rain and snow affect visibility as well as signal reception from radar and other electronic positioning equipment. These effects are unforeseeable and often localized; they may move about and be of a variable duration.

## 3.3 Environmental impact

The Pilotage Risk Management Methodology defines a risk scenario as "a defined sequence of events[3] with an associated frequency[4] and consequences[5]" (Transport Canada, 2001). Each event has a cause and a source (i.e., hazards).

### 3.3.1 *Identification of hazards*

In risk analysis it is important to break events down into hazards and sometimes go back to the source of those hazards. This in-depth analysis makes it possible to identify all the factors contributing to the event and aggravating its consequences. It also provides a better understanding of all the parameters and a better evaluation of the two components of risk, namely the probability of occurrence[6] of an event and the severity of its consequences.

PRMM defines hazard as "a source of potential harm, or a situation with a potential for causing harm, in terms of human injury, damage to health, property, the environment, and other things of value, or some combination of these" (Transport Canada, 2001, p. iii).

A review of accident reports shows that most events arise from a combination of factors which we are calling "hazards". Sometimes the hazards act additively and sometimes synergistically.

Every event, no matter what its nature, is generated by one or more hazards, which may be of diverse origin. The hazards may act independently of each other, producing an additive effect (effect associated with hazard A + effect associated with hazard B = overall effect of A+B), or they may interact and amplify the effects of the others, thus producing a synergistic effect (effect associated with hazard A + effect associated with hazard B < overall effect of A+B) (Axys Environmental Consulting *et al.*, 2000). Also, the effects of certain hazards are sometimes amplified by other factors known as "aggravating factors". The notion of aggravating factor will be further discussed in section 6.1.2.

---

[3] Facts from which a specific situation arises that may lead to damage.
[4] Number of occurrences of an event.
[5] Damage resulting from an event.
[6] Chances of seeing the event occur.

Marine hazards, and specifically those related to pilotage on the St. Lawrence, are many and varied. For this study we used numerous documents to identify the navigational hazards on the St. Lawrence River:

- reports of accidents that have occurred on the St. Lawrence;
- reports of accidents abroad;
- data retrieved from the MARSIS database on marine accidents;
- submissions made as part of this present project or similar projects carried out earlier or in other regions.

The literature review, together with the analysis of the accident reports and the databases, yielded a list of items identifiable as potential hazards associated with navigating on the St. Lawrence. We have grouped them in three categories:

- hazards associated with natural factors (physical features of natural or man-made origin);
- hazards associated with human factors (human behaviour and abilities);
- hazards associated with technical factors (mechanical, technical and technological problems).

The identified hazards are listed in Table 3. The natural hazards are in many cases specific to particular portions of the St. Lawrence River.

Table 4 shows the characteristics of the pilotage districts and the hazards associated with each of them. This information is drawn from the risk assessment report by DDH Environnement Ltée (2002), the report published by the Société linnéenne du Québec and Les Amis de la vallée du Saint-Laurent (2003), and the reports published by the Corporation of Mid St. Lawrence Pilots (2002 and 2003) and the Corporation of Lower St. Lawrence Pilots (2003).

Table 3 – Hazards associated with navigating on the St. Lawrence River

| *Description of hazard* | *Natural* | *Human* | *Technical* |
|---|---|---|---|
| Depth of channel / presence of shoals | X | | |
| Width of channel (narrowness) | X | | |
| Sinuousness of track | X | | |
| Tide | X | | |
| Speed and direction of currents | X | | |
| Water level | X | | |
| Cross-currents | X | | |
| Wind and waves | X | | |
| Reduced visibility at night | X | | |
| Visibility (rain, fog, mist, snow, freezing rain, etc.) and weather conditions | X | | |
| Presence of ice | X | | |
| Nature of bottom and sides | X | | |
| Density of traffic and types of ships encountered | X | | |
| Ferry traffic | X | | |
| Pleasure boats (summer) | X | | |
| Presence and quality of navigational aids | X | | |
| Configuration of port facilities | X | | |
| Presence of obstacles (natural or artificial) | X | | |
| Duration of trip | X | X | |
| Ignorance of environmental features and weather conditions | X | X | |
| Lack of knowledge of the ship and its navigating equipment | | X | |
| Inaccurate assessment of ship's position | | X | |
| Cooperation between pilots and bridge officers | | X | |
| Communication between pilots and bridge officers | | X | |
| Language of communication | | X | |
| Fatigue | | X | |
| Stress | | X | |
| Erroneous estimate of conditions (tide, wind) | | X | |
| Workload too great, too much information to consider | | X | |
| Inattention while steering ship | | X | |
| Contradictory surveys | | X | |
| Disagreement or misunderstanding among team members | | X | |
| Passage plan not followed or poorly defined, preparations for trip | | X | |
| Operating error, course alteration at wrong point | | X | |
| Communication with the outside world | | X | |
| Anchoring in places having underwater infrastructure | | X | |
| Lack of knowledge of docks and their approaches | | X | |
| Acts of sabotage or terrorism | | X | |
| Position report not transmitted | | X | |
| Wrong estimate of distances when passing another ship | | X | |
| Profitability and competitiveness considerations | | X | |
| Misreading instruments | | X | |
| Total or partial loss of power ("black-out") | | | X |

| *Description of hazard* | *Natural* | *Human* | *Technical* |
|---|---|---|---|
| Total or partial loss of navigational instruments | | | X |
| Positioning error through wrong setting of navigating instruments | | | X |
| Total or partial loss of rudder control | | | X |
| Failure of engine-room telegraph | | | X |
| Failure of navigation aids | | | X |
| Limited beaconing in winter | | | X |
| Defective electrical system | | | X |
| Failure of compressor or other equipment | | | X |
| Failure of ship's structure | | | X |
| Poor distribution of cargo | | | X |
| Ship's manoeuvrability | | | X |
| Ship's configuration | | | X |
| Ship's size | | | X |

Table 4 – Summary of hazards associated with different sections of the St. Lawrence

| *Description of hazard* | *Port of Montreal* | *Montreal/ Trois-Rivières* | *Trois-Rivières/ Quebec City* | *Port of Quebec City* | *Quebec City/ Les Escoumins* | *Saguenay River* |
|---|---|---|---|---|---|---|
| Depth of channel/presence of shoals | X | X | X |  | X |  |
| Width of channel | X | X | X |  |  |  |
| Sinuousness of track |  | X | X |  |  |  |
| Tides |  |  | X | X | X | X |
| Speed and direction of currents | X | X |  |  | X |  |
| Water level |  |  |  |  |  |  |
| Cross-currents | X | X | X |  | X |  |
| Wind – waves |  |  |  |  |  |  |
| Reduced visibility at night | X |  |  | X |  |  |
| Visibility (rain, fog, mist, snow, freezing rain, etc.) and weather conditions | X |  | X |  | X | X |
| Presence of ice | X | X | X | X | X | X |
| Nature of bottom and sides |  | X | X |  |  |  |
| Traffic density and types of ship encountered | X | X | X | X | X | X |
| Ferry traffic |  | X |  | X | X |  |
| Pleasure boats (summer) | X |  |  | X | X |  |
| Presence and quality of navigational aids |  | X | X |  | X |  |
| Configuration of port facilities | X |  |  | X |  |  |
| Presence of obstacles (natural or artificial) | X | X | X |  |  |  |

### 3.3.2 *Identification of types of consequences and types of damage*

As already mentioned, PRMM defines a risk scenario as "a defined sequence of events with an associated frequency and consequences" (Transport Canada, 2001, p. iii). When developing risk scenarios, it is therefore vital to identify the consequences that generally arise from critical navigational situations on the St. Lawrence River, in particular those related to pilotage, and to be aware of the kinds of damage that may result.

#### 3.3.2.1 Consequences

Analysis of the information in the MARSIS database, and of the various documents consulted on the subject (DDH Environnement 2002, Société linnéenne du Québec and Les Amis de la vallée du Saint-Laurent 2003, Corporation of Mid St. Lawrence Pilots 2002 and 2003, Corporation of Lower St. Lawrence Pilots 2003) shows that, generally speaking, marine accidents may result in the following consequences:

- bottom contact;
- grounding;
- collision with a ship or boat;
- collision with infrastructure (dock, bridge pier, crane, etc.);
- capsizing;
- fire and/or explosion;
- shipwreck.

These consequences may affect to varying degrees the health and safety of employees and the public, the environment, productivity, the condition of equipment and infrastructures, and so on. It is therefore vital, when considering the risk associated with a given situation, to assess the scope and severity of the consequences.

For a given event, the consequences and their severity may vary with:

- the physical/ecological features of the place where the event occurred;
- the width, depth and sinuousness of the channel at the place where the event occurred;
- navigating conditions prevailing at the time of the event;
- type of ship and cargo;

- ship's navigation characteristics and manoeuvrability;
- nearby marine traffic;
- presence of infrastructures;
- speed of corrective action.

#### 3.3.2.2 Damage

Industrial pollution from tankers and barges transporting chemical and petroleum products represents only a very small portion of global water pollution. However, a single large spill in the St. Lawrence could be catastrophic. In 1990 the Brander-Smith Review Panel (Brander-Smith et al., 1990) pointed out that emergency plans and exercises were not sufficiently detailed and precise to ensure protection in case of a major spill.

Judson, Shortreed & Reid (1999) estimated that if 1500 $m^3$ of heating oil were spilled in Lake Saint-Pierre, the total cost of cleaning up the river and banks and paying civil damage suits would be $22.2 million, including fines for damage to the environment, which could total up to $1 million. The authors also estimated the probability of a collision in the Pointe-aux-Ormes area at 0.36 a year, which means one event every three years. Damages to the ships themselves as a result of a collision would cost $2 million a year, not to mention the environmental and social consequences.

Generally speaking, the possible consequences of a grounding or a collision with a structure or with another ship are numerous and their severity will depend on the event itself and on the conditions under which it occurred. In the case of a collision between ships, the potential kinds of damage are: loss of life, partial or total obstruction of the channel, explosion and fire, material damage to the ships, their equipment or their cargoes, disturbance or destruction of the aquatic environment by pollution, and disturbance of drinking water supply lines. In the case of a ship colliding with a structure, the following additional damage may occur: interruption of port operations, damage to heritage (e.g., Quebec City bridge), and loss of public utilities (Société linnéenne du Québec and Les Amis de la vallée du Saint-Laurent, 2003).

By far the most difficult kind of damage to assess is pollution of the aquatic environment by ships' cargoes. The St. Lawrence River is a national priority as regards ecological diversity and as regards commercial and recreational/tourist activities. It is frequented by over 260 species of birds and it is home to over 240 species of aquatic life. It is hard to imagine the extent of the consequences of a large spill, but the situation would certainly be worse than would occur with a spill at sea, in that cleaning up soft soil and islands is a greater technological challenge than cleaning up the rocky coastline of an ocean. In the case of an oil spill, both shores of the St. Lawrence would be contaminated over and over again as a result of the tides. Also, use of an oil slick boom would not be very effective, because of strong currents or ice (Société linnéenne du Québec et Les Amis de la vallée du Saint-Laurent, 2003).

Oil slicks would contaminate the banks for years and thus ruin the region's tourist potential, not to mention the harm that would be done to the shipping industry. Whole communities of birds might be affected (Brander-Smith et al., 1990). Destruction of micro-organisms at the base of the food chain would imperil organisms higher on the chain, starting with fish stocks and their spawning grounds.

Contamination of the shores would also destroy marshlands which, in addition to being of incomparable ecological richness, attract numerous species of migratory birds. These are complex ecosystems that also contribute to maintaining the water table and mitigating the effects of flooding and erosion. Also, some marshes, such as the Cap Tourmente reserve and the Baie de l'Île Verte reserve, are world heritage sites.

More than 30 types of hazardous goods are shipped along the St. Lawrence River (Paul et Guerrier, 2000). The properties of these chemicals and petroleum products are such that, if spilled, they dissolve in water and/or thicken and/or react with the water to form toxic compounds. In addition to causing considerable damage to the environment, some of these products may pose significant risks to the public in view of the many drinking water intakes. For example, sulphuric acid is viscous and denser than water and may therefore contaminate water intakes at the river bottom. Another example: sodium cyanide is soluble, sinks quickly and reacts with water to form a toxic gas, hydrogen cyanide. In Quebec, 45% of the population gets its drinking water from the St. Lawrence. It is also worth noting that some products not classified as hazardous may nonetheless have harmful effects if spilled.

The St. Lawrence harbours numerous threatened species, such as the beluga, the harbour porpoise and the humpback whale. There are also many bird sanctuaries here: the Saguenay – St. Lawrence Marine Park, the Charlevoix Biosphere Reserve, and the St. Lawrence Estuary Marine Protected Area. Thus any large-scale spill could pose a threat to the environment.

Table 5 summarizes the kinds of damage generally associated with the previously mentioned consequences. They are drawn from the literature, from the MARSIS database, and from Transportation Safety Board accident reports.

Table 5 – Summary of consequences and associated damage

| *CONSEQUENCES* | *DAMAGE* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Injury* | *Death* | *Material damage to ship and/or cargo* | *Material damage to infrastructures* | *Obstruction of navigating channel* | *Delay or loss of revenue* | *Disturbance/ destruction of environment* | *Contamination of water and/or sediment* |
| Touching bottom | X | | X | | | | X | |
| Grounding | X | | X | | X | X | X | X |
| Collision with a ship | X | X | X | | X | X | X | X |
| Collision with infrastructure | X | X | X | X | X | X | X | X |
| Capsizing | X | X | X | | X | X | X | X |
| Fire and/or explosion | X | X | X | | X | X | X | X |
| Shipwreck | X | X | X | | | X | X | X |

## 3.4 Human factors

The human factor is in a way the centrepiece of this study, in view of its purpose and objectives.

A review was made of the literature on this subject as it applies to the activities of pilots. We looked for documentation in three areas: the effects of fatigue on the performance of people carrying out tasks that call for mental effort; the cognitive abilities and performance levels required of a pilot if the job is to be done safely; the place of fatigue and cognitive abilities in the overall dynamics of marine pilotage.

The literature review provided a good overview of all these matters. See Appendix 1.

# 4. Statistical and spatial analyses

An important source of information is the data on past accidents and incidents. Analysis of this data helps identify the hazards and factors leading up to an accident or incident. In addition, statistical and spatial analyses can be performed on the data in order to spot trends or identify cause-effect relationships.

For the purposes of this study, the main sources of information on past accidents and incidents were Transport Canada's MARSIS database and the Transportation Safety Board of Canada's accident reports.

Transport Canada provided an extract from the MARSIS database covering only those accidents and incidents that occurred between Montreal and Les Escoumins, i.e. within the LPA's area of responsibility. This source was supplemented by the Canadian Coast Guard's DADS database, which provides information on vessel transits.

## 4.1 Pre-processing of data

In order to obtain just the information relevant to our risk analysis, the MARSIS data underwent preliminary processing:

- Accidents and incidents that occurred outside the area under study were eliminated;
- Accidents and incidents that occurred when there was no pilot on board were eliminated, but if it is not known whether there was a pilot aboard, the accident/incident was kept;
- Accidents and incidents whose cause has no connection with pilotage were eliminated. To this end, accidents/incidents were sorted by event type, and for some of the types, the commentaries had to be analysed.

## 4.2 Statistical Analysis

Results of the statistical analysis enabled us answer certain questions. They also served to validate the data used for the risk assessment model. See the tables in Appendix 3.

## 4.3 Spatial Analysis

A spatial analysis of accidents/incidents was performed using the MARSIS data. Before the data were processed, however, the origins and destinations of each ship were examined to determine whether the vessel in question was travelling up or down the St. Lawrence or the Saguenay. In the case of ships where information was missing or erroneous (the origin and destination were not related to a transit of the St. Lawrence), the direction of travel was recorded as unknown. See Appendix 4 for the maps produced in connection with our spatial analysis.

Map 1 shows all the accidents and incidents. It clearly shows that the portion of the St. Lawrence River between Montreal and Quebec City has more accidents/incidents than the portion between Quebec City and Les Escoumins. It also reveals that the accidents/incidents are concentrated near ports (Montreal, Sorel, Trois-Rivières, Quebec City and, to a lesser extent, Cacouna and Saguenay).

The findings shown on Map 1 are confirmed by Maps 2, 3 and 3a, which show accidents/incidents by three-year periods. Accidents are concentrated in specific locations, including port areas, while incidents are more evenly distributed, though there is a considerable concentration near the Port of Quebec City. There are no notable trends with respect to the distribution of accidents/incidents over time.

Maps 4 and 5 show the distribution of accidents/incidents in the different areas in terms of whether the ship was moving upstream (map 4) or downstream (map 5). As can be seen, when ships were sailing up the Saguenay, accidents were concentrated near the ends of trips, but when ships were sailing down the Saguenay, accidents occurred at many points, though with a concentration at the river's mouth. No concentrations are found in the Les Escoumins/Quebec City or Quebec City/Trois-Rivières stretches of the St. Lawrence River. In the Montreal/Trois-Rivières stretch, a comparison of Maps 4 and 5 shows that there were more accidents near Sorel and at the entrance to Lake St. Pierre when ships were moving downstream than when they were moving upstream.

Map 6 shows the distribution of accidents/incidents in terms of vessel type. No tendencies or highlights are visible.

# 5. Development of scenarios

This study aims to review and identify all the criteria and circumstances that call for the presence aboard a ship of a second pilot and/or pilotage certificate holder.

The scenarios to be developed in the study had to make it possible to determine whether the addition of a second pilot is the right measure if the risk associated with a given scenario is to be reduced, and to assess the value of other possible risk mitigation measures. All scenarios for which it was not possible to determine the necessity of a second pilot (e.g., act of terrorism or sabotage, accident occurring when no pilot is on board, etc.) were consequently ignored.

## 5.1 Description of risk scenarios

The first step in developing the scenarios was to validate the list of hazards (see Table 3) with stakeholders. This took place during the first round of consultations in the fall of 2003. The list was then discussed and additions were made.

Based on comments made during the consultations, the most relevant hazards were selected. Some of the hazards can be deemed "aggravating factors" (contributing factors), that is, they do not cause the event but rather facilitate its occurrence and/or amplify its consequences.

During the consultations it was established that some of the aggravating factors may be indicators of conditions under which a scenario attains a degree of risk such that a second pilot is needed on the bridge or some other risk mitigation measure is required. This is why the aggravating factors were considered during development of the scenarios.

For the purposes of our study, elements such as fatigue, stress and work overload were not deemed to be hazards in themselves but rather aggravating factors or error-producing conditions associated with human factors.

This methodological choice may be justified as follows:

- fatigue, stress or work overload are factors that may lead to a failure to act or to an act that is inappropriate in a given situation; it is this failure or inappropriate act that constitutes the hazard that leads to the accident/incident;

- fatigue, stress or work overload may aggravate an existing situation, through lack of vigilance or a reaction that is inappropriate or too slow.

Furthermore, since the purpose of creating the scenarios is to determine the need for a second pilot, it would seem to be a good idea to place the human beings involved (pilots and crews) at the centre of our analysis. Thus all the scenarios developed are ones that arise from hazards associated with human factors. The same is true for the model created to analyse the risk scenarios. Other hazards (natural, technical, certain human factors) are seen as aggravating factors. Aggravating conditions and factors that are related to the duration of the trip (fatigue, stress, work overload, area navigated, ship's characteristics, etc.) are used in the analytical model (see Section 6) as well.

Thus the following assumptions underlie the present study and the methodology for analysing the scenarios:

- Accidents are not caused by natural or technical factors but by a failure to act, a misinterpretation, a human error or a manoeuvre that is not appropriate under the given environmental conditions or other specific circumstances;
- Natural or technical factors contribute to risk scenarios as aggravating factors.

Table 6 lists the hazards used in the study and identifies those deemed to be aggravating factors.

Table 6 – Hazards and aggravating factors selected for development of scenarios

| *Description of hazard* | *Natural* | *Human* | *Technical* | *Aggravating factor* |
|---|---|---|---|---|
| Depth of channel / presence of shoals | X | | | X |
| Width of channel (narrowness) | X | | | X |
| Sinuousness of track | X | | | X |
| Tide | X | | | X |
| Speed and direction of currents | X | | | X |
| Water level | X | | | X |
| Cross-currents | X | | | X |
| Wind and waves | X | | | X |
| Reduced visibility at night | X | | | X |
| Visibility (rain, fog, mist, snow, freezing rain, etc.) and weather conditions | X | | | X |
| Presence of ice | X | | | X |
| Nature of bottom and sides | X | | | X |
| Density of traffic and types of ships encountered | X | | | X |
| Ferry traffic | X | | | X |
| Pleasure boats (summer) | X | | | X |
| Presence and quality of navigational aids | X | | | X |
| Configuration of port facilities | X | | | X |
| Presence of obstacles (natural or artificial) | X | | | X |
| Duration of trip | | X | | X |
| Ignorance of environmental features and weather conditions | | X | | X |
| Lack of knowledge of the ship and its navigating equipment | | X | | X |
| Inaccurate assessment of ship's position | | X | | |
| Cooperation between pilots and bridge officers | | X | | X |
| Communication between pilots and bridge officers | | X | | X |
| Language of communication | | X | | X |
| Fatigue | | X | | X |
| Stress | | X | | X |
| Erroneous estimate of conditions (tide, wind) | | X | | |
| Workload too great, too much information to consider | | X | | X |
| Inattention while steering ship | | X | | |
| Contradictory surveys | | X | | |
| Disagreement or misunderstanding among crew members | | X | | |
| Passage plan not followed or poorly defined, preparations for trip | | X | | |
| Operating error, course alteration at wrong point | | X | | |
| Communication with the outside world | | X | | |
| Anchoring in places having underwater infrastructure | | X | | |
| Lack of knowledge of docks and their approaches | | X | | X |
| Acts of sabotage or terrorism | | X | | |
| Position report not transmitted | | X | | |

| *Description of hazard* | *Natural* | *Human* | *Technical* | *Aggravating factor* |
|---|---|---|---|---|
| Wrong estimate of distances when passing another ship | | X | | |
| Profitability and competitiveness considerations | | X | | X |
| Misreading instruments | | X | | |
| Total or partial loss of power ("black-out") | | | X | X |
| Total or partial loss of navigational instruments | | | X | X |
| Positioning error through wrong setting of navigational instruments | | | X | X |
| Total or partial loss of rudder control | | | X | X |
| Failure of engine-room telegraph | | | X | X |
| Failure of navigation aids | | | X | X |
| Limited beaconing in winter | | | X | X |
| Defective electrical system | | | X | X |
| Failure of compressor or other equipment | | | X | X |
| Failure of ship's structure | | | X | X |
| Poor distribution of cargo | | | X | X |
| Ships's manoeuvrability | | | X | X |
| Ship's configuration | | | X | X |
| Ship's size | | | X | X |

In considering the human aspects at the centre of this study, the risk scenarios have to identify the human factors at the origin of the event as well as the aggravating factors that contributed to the situation, and they must be able to show the value of a second pilot or other risk mitigation measure.

If the scenarios are to serve these purposes, the answer to at least one of the following questions must be "yes":

- Did the pilot commit a piloting error?
- Did the pilot misjudge the navigating conditions or ice conditions?
- Did the pilot have the experience or training needed to navigate under these conditions?
- Was the pilot fatigued or stressed, and might that fatigue or stress have negatively affected the pilot's judgment during a manoeuvre?
- Did the pilot have such a large workload so as not to be able to take into consideration all aspects of the situation, or so as to have underestimated them?
- Was the pilot working in an environment in which his or her duties could not be effectively carried out?

If the answer to one of the questions is yes, one can then go on to ask whether a second pilot would have prevented the accident/incident or whether it was inevitable (i.e., no matter how experienced or vigilant the second pilot, it would have made no difference).

Five scenarios were developed based on the identified hazards and aggravating factors. All five revolve around a hazard associated with human factors related to the pilot's tasks, including the pilot's reactions to unforeseen circumstances and critical situations that may arise.

The first step was to identify the pilot's tasks. This was done on the basis of the three-volume report entitled *Pilotage Certificate Training for the Laurentian Region*, TP 13458E (Audet and Victor, 1999). The following tasks (groups of tasks) were identified:

- Prepare for trip
- Prepare passage plan
- Inform bridge officers of navigating conditions
- Establish trust between pilot and bridge officers
- Determine ship's manoeuvrability, behaviour and performance
- Check precision of instruments
- Obtain information from Marine Communications and Traffic Services (MCTS)
- Determine when the course should be changed to deal with the current
- Determine the time required to move through risky areas
- Navigate
- Validate the position of the ship
- Analyze information provided by the crew and by MCTS
- Report to MCTS
- Give helmsman orders
- Assess weather conditions and navigate accordingly
- Change pilots if necessary
- Make docking manoeuvres
- Make anchoring manoeuvres
- Assess need to use tugs
- Assess special situations
- Manoeuvre to avoid catastrophe in emergency situations
- Inform MCTS of emergencies

- Assess potential harm to the environment
- Update knowledge of emergency measures

Only those scenarios that are the most likely to occur and give rise to adverse consequences were selected. These are listed in Table 7. A detailed description, together with the parameters considering in developing the scenarios, is given in Appendix 5. Note that the scenarios were tested on a navigation simulator to ensure their realism, especially with regard to manoeuvres and reaction times.

Table 7 – Scenarios

| *INITIAL ERROR* | *SECOND ERROR* | *SUMMARY* |
|---|---|---|
| *Scenario 1* | | |
| Wrong manoeuvre ordered | Pilot did not validate the ship's position following the erroneous manoeuvre | The pilot on a tanker between Montreal and Trois-Rivières gives the helmsman an erroneous order. Before the error can be completely corrected, the ship leaves the channel and runs aground. |
| *Scenario 2* | | |
| Order not executed properly by helmsman | Pilot did not notice the helmsman's error | The pilot on a tanker between Montreal and Trois-Rivières gives the helmsman an order. The helmsman makes a mistake while executing the order. The pilot does not notice the mistake in time. Before the error can be noticed and completely corrected, the ship leaves the channel and runs aground. |
| *Scenario 3* | | |
| Positioning error | Wrong manoeuvre ordered | As a result of the changed position of certain buoys in the Grondines sector, the pilot of a bulker misjudges the ship's position. He alters course at the wrong location. The course cannot be adjusted in time and the ship leaves the channel and runs aground. |
| *Scenario 4* | | |
| Misinterpretation of navigating conditions | Pilot mistimed his order to the helmsman | A container ship is approaching Île-aux-Coudres. Three pleasure boats are moving toward the marina and a vessel is approaching from the other direction. The pilot on the container ship misjudges the time and distance required to change course. The ship risks collision with the vessel approaching from the other direction. |
| *Scenario 5* | | |
| Pilot misjudged the moment when a critical point would be passed | Bad docking manoeuvres | The pilot and the master of a small oil tanker did not agree ahead of time on the docking manoeuvres for Saint-Romuald and they are not working together. The ship hits the dock and there is a spill. |

## 5.2 Consequences and severity

Each of the scenarios was discussed and analysed to determine its most likely consequences and their severity. To this end fault trees were prepared for each scenario. These may be found in Appendix 8.

The severity assessment is based on the calculation shown in Table 8, taking into account the impact on safety, public health, the environment and the economy.

Table 8 – Calculation of severity of consequences

| *Consequences for public and employees* | | *Weight* |
|---|---|---:|
| Injuries or effects on health | None | 0 |
| Injuries or effects on health | Minor | 1 |
| Injuries or effects on health | Major | 5 |
| Injuries or effects on health | Severe or risk of death | 10 |

| *Economic consequences* | *Weight* |
|---|---:|
| None | 0 |
| Less than $100 000 | 1 |
| Between $100 000 and $1M | 2 to 3 |
| Between $1M and $10M | 4 to 9 |
| Over $10M | 10 |

| *Environmental consequences / drinking water* | *Weight* |
|---|---:|
| No consequences | 0 |
| Minor (see table below) | 1 |
| Moderate (see table below) | 5 |
| Major (see table below) | 10 |

*Evaluation of environmental consequences*

| | *Extent of consequences (e.g., of spill)* | | |
|---|---|---|---|
| | *Small* | *Medium* | *Large* |
| Temporary effect (short term) | Minor | Minor | Moderate |
| Temporary (medium term) | Minor | Moderate | Major |
| Permanent effect | Moderate | Major | Major |

The consequences of each scenario and their severity are shown in Table 9.

Table 9 – Consequences of scenarios and their severity

| *Scenario* | *Consequences* | *Severity (public/ environment/ economy)* |
|---|---|---|
| Scenario 1:<br>wrong order given | – grounding | 2/8/7: total 17 |
| Scenario 2:<br>order not execuied correctly | – grounding | 2/8/7: total 17 |
| Scenario 3:<br>positioning error | – grounding | 1/5/7: total 13 |
| Scenario 4:<br>misinterpretation of navigating conditions | – collision with ship avoided | 0/0/0: total 0 |
| Scenario 5:<br>bad docking manoeuvre | – collision with infrastructure | 2/10/10: total 22 |

# 6. Risk analysis model

A risk analysis model was developed for the purpose of determining the probability of occurrence of the various scenarios. The model, which is based in part on the Human Error Analysis and Reduction Technique (HEART) developed by Williams (1988), calculates the risk associated with scenarios on the basis of the following:

- aggravating factors involved;
- type of ship and its manoeuvrability;
- section of the river;
- duration of the transit;
- presence on board of one pilot;
- presence on board of two pilots;
- presence on board of one pilot along with the use of other risk mitigation measures.

Since the model can simultaneously analyse all three possibilities (one pilot, two pilots, one pilot plus other measures), it can assign a value to the contribution made by the second pilot as well as the effectiveness of any other risk mitigation measure. Figure 2 shows the model interface.

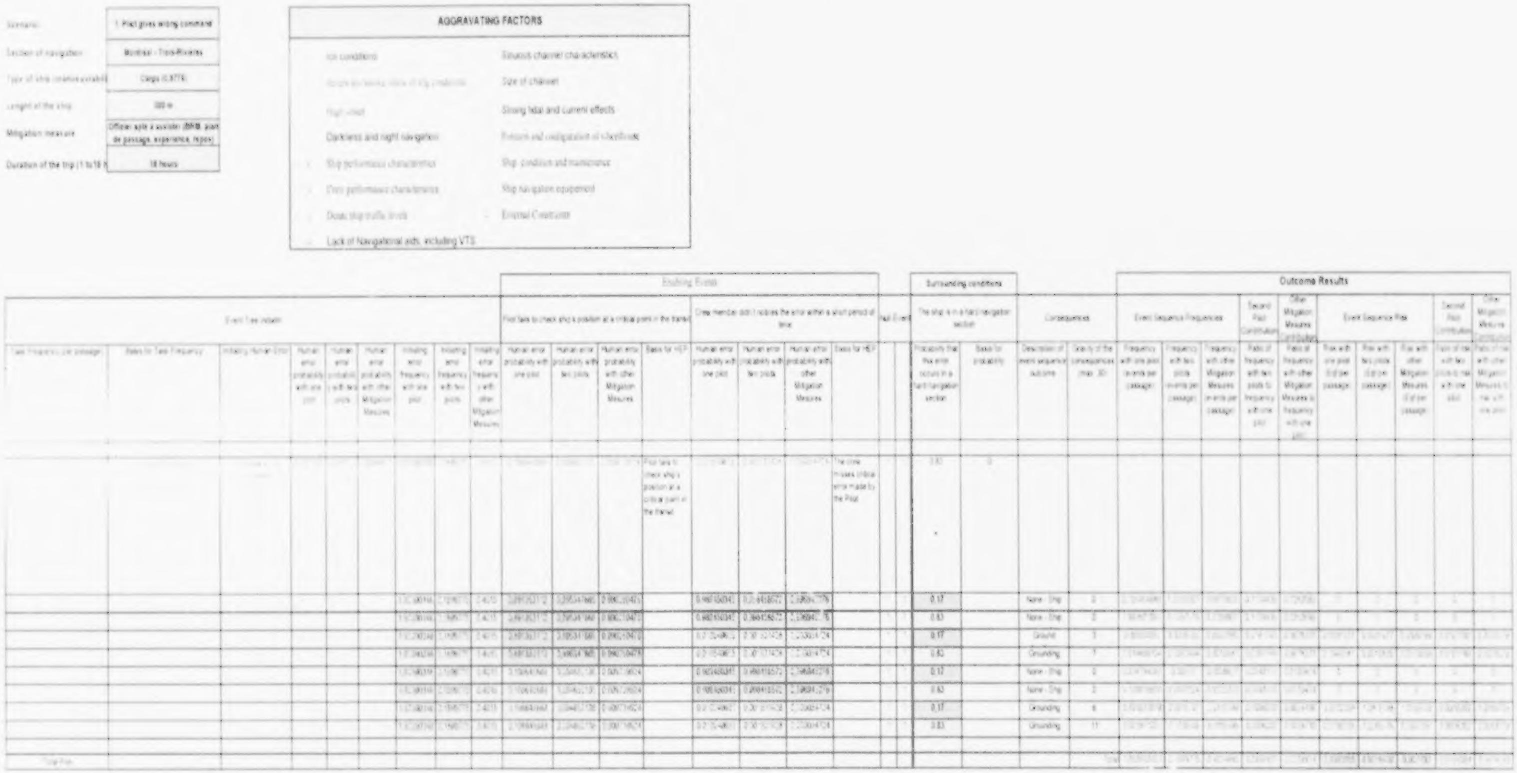
## 6.1 Components of the model

The core of the model is the Human Error Analysis and Reduction Technique. A variety of specific calculations are then added to cover the various points shown in Figures 2 and 3.

AGGRAVATING FACTORS

Figure 2 – Risk analysis model

# Figure 2 – Risk analysis model



| | |
|---|---|
| Scenario: | 1. Pilot gives wrong command |
| Section of navigation: | Montréal - Trois-Rivières |
| Type of ship (relative probabili | Cargo (0.8776) |
| Length of the ship: | 300 m |
| Mitigation measure | Officier apte à assister (BRM, plan de passage, expérience, repos) |
| Duration of the trip (1 to 18 h | 18 hours |

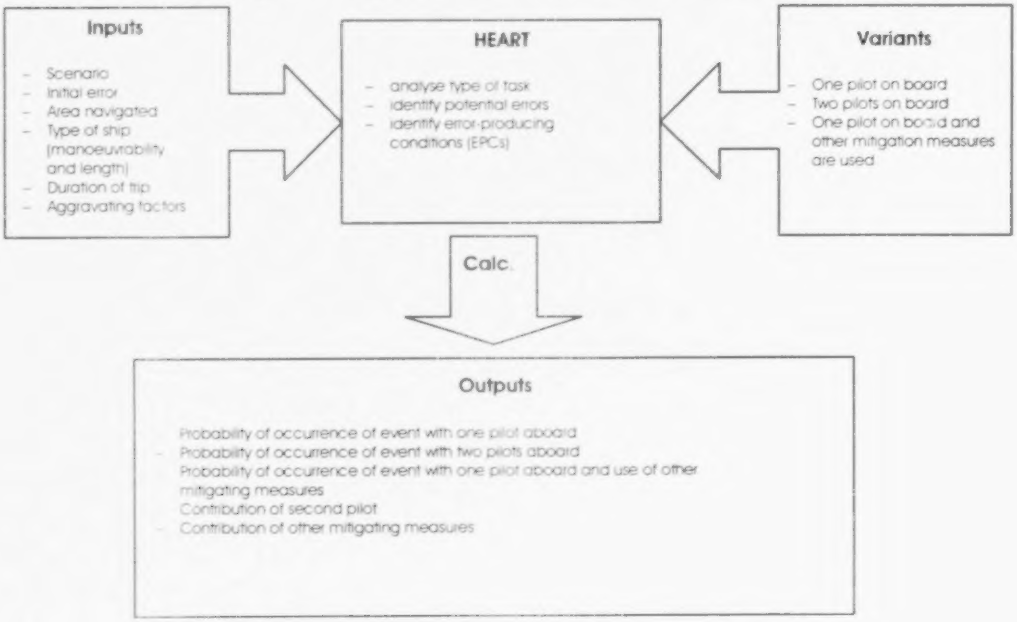
**AGGRAVATING FACTORS**

| | |
|---|---|
| Ice conditions | Sinuous channel characteristics |
| [illegible] | Size of channel |
| High wind | Strong tidal and current effects |
| Darkness and night navigation | [illegible] |
| Ship performance characteristics | Ship condition and maintenance |
| Crew performance characteristics | Ship navigation equipment |
| Dense ship traffic levels | External Constraints |
| Lack of Navigational aids, including VTS | |

The model is based on information gleaned from the literature and from comments expressed during consultations about the following:

- hazards;
- aggravating factors;
- scenarios;
- mitigation measures;
- etc.

Figure 3 – Logical structure of the risk analysis model


Inputs
- Scenario
- Initial error
- Area navigated
- Type of ship (manoeuvrability and length)
- Duration of trip
- Aggravating factors
HEART
- analyse type of task
- identify potential errors
- identify error-producing conditions (EPCs)
Variants
- One pilot on board
- Two pilots on board
- One pilot on board and other mitigation measures are used
Calc.
Outputs
- Probability of occurrence of event with one pilot aboard
- Probability of occurrence of event with two pilots aboard
- Probability of occurrence of event with one pilot aboard and use of other mitigating measures
- Contribution of second pilot
- Contribution of other mitigating measures

### *6.1.1 Human Error Analysis and Reduction Technique*

HEART calculates the probability of occurrence of human errors depending on the specific tasks involved (see chapter 5). It takes into account:

- the type of task;
- the uncertainty associated with each type of task;
- potential errors;
- error-producing conditions (EPCs);

- the effect of the EPCs on the probability of occurrence;
- the weight associated with each EPC.

The data come from the tables in Williams (1988). Appendix 2 gives the tables along with details on the calculation of the probability of occurrence of human error.

Table 10 sets out the data that were used to calculate the probabilities of occurrence of human error in the present study. The data on each of the tasks described in chapter 5 were entered in the model even if the scenarios do not include a given task. The scenarios can easily be adjusted as the need arises.

Table 10 – Data for calculating probability of occurrence using HEART

| *Type of task* | *Prob. related to type of task* | *Error* | *EPC No* | *Effect of EPC* | *Weight of EPC** |
|---|---|---|---|---|---|
| Preparations for transit | F<br>0.0030 | Positioning error | 1 | 17 | 0.01 |
| | | | 2 | 11 | 0.30 |
| | | | 16 | 3 | 0.20 |
| | | | 17 | 3 | 0.20 |
| | | | 18 | 3 | 0.20 |
| | | | 19 | 3 | 0.05 |
| | TC<br>0.0010 | Pilot misjudged moment when a critical point would be passed | 2 | 11 | 0.30 |
| | | | 10 | 5.5 | 0.20 |
| | | | 18 | 3 | 0.20 |
| Navigation | G<br>0.0004 | Pilot did not validate ship's position after a wrong manoeuvre | 1 | 17 | 0.10 |
| | | | 2 | 11 | 0.30 |
| | | | 3 | 10 | 0.25 |
| | | | 5 | 8 | 0.25 |
| | | | 8 | 6 | 0.25 |
| | | | 16 | 3 | 0.20 |
| | | | 17 | 3 | 0.20 |
| | | | 18 | 3 | 0.20 |
| | | Misinterpretation of navigating conditions | 1 | 17 | 0.10 |
| | | | 2 | 11 | 0.30 |
| | | | 3 | 10 | 0.25 |
| | | | 5 | 8 | 0.25 |
| | | | 8 | 6 | 0.25 |
| | | | 16 | 3 | 0.20 |
| | | | 17 | 3 | 0.20 |
| | | | 18 | 3 | 0.20 |
| | | | 19 | 3 | 0.05 |

| *Type of task* | *Prob. related to type of task* | *Error* | *EPC No* | *Effect of EPC* | *Weight of EPC** |
|---|---|---|---|---|---|
| Navigation | G<br>0.0004 | Pilot ordered wrong manoeuvre | 1 | 17 | 0.10 |
| | | | 2 | 11 | 0.30 |
| | | | 16 | 3 | 0.20 |
| | | | 17 | 3 | 0.20 |
| | | | 18 | 3 | 0.20 |
| | | | 19 | 3 | 0.05 |
| | | Pilot did not notice helmsman's error | 1 | 17 | 0.10 |
| | | | 2 | 11 | 0.30 |
| | | | 8 | 6 | 0.20 |
| | | | 16 | 3 | 0.20 |
| | | | 17 | 3 | 0.20 |
| | | | 18 | 3 | 0.20 |
| | | | 19 | 3 | 0.05 |
| | | Pilot mistimed his order to the helmsman | 1 | 17 | 0.10 |
| | | | 2 | 11 | 0.30 |
| | | | 8 | 6 | 0.20 |
| | | | 17 | 3 | 0.20 |
| | | | 18 | 3 | 0.20 |
| Special situations | C<br>0.1600 | Bad docking manoeuvre | 1 | 17 | 0.05 |
| | | | 2 | 11 | 0.05 |
| | | | 3 | 10 | 0.05 |
| | | | 8 | 6 | 0.05 |
| | | | 10 | 5.5 | 0.05 |
| | | | 16 | 3 | 0.10 |
| | | | 17 | 3 | 0.10 |
| | | | 18 | 3 | 0.20 |
| | | | 19 | 3 | 0.05 |
| Helmsman's task | E<br>0.0200 | Order not executed properly by helmsman | 2 | 11 | 0.20 |
| | | | 16 | 3 | 0.10 |
| | | | 17 | 3 | 0.10 |
| | | | 18 | 3 | 0.20 |

* Values given as exemples

The letters C, E, E, F, G and TC designate task types. They are defined in Table 4 of Appendix 2.

### *6.1.2 Impact of aggravating factors*

During the initial work and consultations, several hazards were identified as aggravating factors (see Table 6). These were incorporated into the model in order to be able to evaluate their impact.

When the aggravating factors are applied to a specific scenario, they magnify the effects of the Error Producing Conditions. Their impact on an EPC is expressed as a percentage of the total effect attributable to that EPC. Table 11 gives the values used to express these impacts. The values were determined by the *Innovation maritime* team based on the comments received during the consultations. So, for example, fog represents 30% of the potential sources of background noise.

In addition to being affected by the aggravating factors shown on Table 11, some of the EPCs (time pressure, workload, fatigue) are affected by factors such as the ship's manoeuvrability and the duration of the transit. The influence of these factors was analysed separately because they are always present.

### Manœuvrability of ship

The bigger or less manoeuvrable a ship, the greater the influence of the ship itself will be on the EPCs and on the probability of an accident/incident occurring.

The length and manoeuvrability of a ship affect the speed of its response. To determine the level of risk associated with a ship in a given situation, it is therefore vital to assign a value to its manoeuvrability. The methodology for assigning such a value is set out in Appendix 6.

Each ship is assigned a manoeuvrability coefficient. There is a module where the length can be set, and the model then calculates the real manoeuvrability based on the length and the coefficient arising from the tests described in Appendix 6.

The model uses the following manoeuvrability coefficients:

| | |
|---|---|
| • Oil tanker | 0.7133 |
| • Oil tanker | 1.0 |
| • Oil tanker | 1.5322 |
| • Container ship | 0.8727 |
| • Container ship | 1.2790 |
| • Bulker | 1.0331 |
| • Cargo | 0.9775 |
| • Ro-ro | 0.8588 |
| • Passenger | 1.00 |

## Table 11 – Influence of aggravating factors

| | *Error-Producing Conditions (EPC)* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *EPC No* | *1* | *2* | *3* | *5* | *8* | *10* | *16* | *17* | *18* | *19* |
| *Influence on EPCs* | *New situation* | *Pressure due to time* | *Background noise* | *Display of information* | *Workload/ capacity* | *Transfer of information and knowledge* | *Failure of interpersonal communication* | *No checking of data or actions* | *Fatigue* | *Over-confidence* |
| Aggravating factors | | | | | | | | | | |
| Ice | | | 0.2 | | 0.0625 | 0.055 | | 0.1 | 0.08 | 0.1 |
| Fog, reduced visibility | | 0.12 | 0.3 | 0.2 | 0.1 | 0.03 | | | 0.1 | 0.1 |
| High winds | | | | | 0.0625 | 0.02 | | | 0.02 | |
| Darkness and night navigation | | | 0.15 | 0.2 | 0.06 | 0.02 | | | 0.1 | 0.1 |
| Ship's performance characteristics | 0.15 | 0.12 | | | 0.025 | 0.15 | | | 0.1 | 0.1 |
| Crew's characteristics | | 0.08 | | | 0.0625 | 0.1 | 0.65 | 0.05 | 0.05 | 0.1 |
| Traffic density | | 0.12 | | | 0.0625 | 0.055 | | | 0.1 | 0.1 |
| Lack of navigational aids | | 0.05 | 0.05 | 0.2 | 0.05 | 0.1 | 0.2 | 0.2 | 0.05 | |
| Sinuous channel | | 0.12 | | | 0.08 | 0.01 | | | 0.1 | 0.1 |
| Size of channel | | 0.12 | | | 0.08 | 0.01 | | | 0.085 | 0.1 |
| Currents and tides | | 0.12 | | | 0.08 | 0.01 | | | 0.085 | 0.1 |
| Position and configuration of bridge | 0.1 | 0.03 | 0.05 | 0.2 | 0.0625 | 0.1 | | | 0.03 | |
| Condition of ship | | | | | 0.05 | 0.1 | | | 0.03 | |
| Navigating equipment | 0.75 | 0.12 | 0.125 | 0.2 | 0.0625 | 0.2 | | | 0.05 | 0.1 |
| External constraint | | | 0.125 | | 0.1 | 0.04 | 0.15 | 0.2 | 0.02 | |

Note that the under-keel clearance has deliberately not been taken into consideration, because obtaining a useful value would require taking into consideration too many components: real draft, water density, bathymetry and water level, not to mention squat. It would be very hard to incorporate all these items into the existing model.

While under-keel clearance is, of course, related to risk level, the minimal under-keel clearance for navigating on the St. Lawrence is set by the Canadian Coast Guard. This enables the Coast Guard to manage the risk arising from under-keel clearance regardless of the number of pilots aboard.

It would be useful at a later stage to incorporate risk due to under-keel clearance in the double pilotage risk management model.

#### Duration of transit

It was shown in Chapter 3 that the pilot's transit time is directly related to his or her level of fatigue and consequently to his or her reaction time and degree of vigilance.

During the consultations with stakeholders, duration of transit was also mentioned as an important factor in analysing risk.

A duration-related factor was included in the model based on data concerning the effect of fatigue on pilot vigilance. Vigilance was preferred over reaction time since a reduction in vigilance can cause an omission or a wrong decision, potentially creating a critical situation.

The vigilance reduction levels used in the model are set out in Appendix 1. The pilot's level of fatigue is calculated directly from the transit time. Transits may be between 1 and 18 hours.

### *6.1.3 Sector of navigation*

Since each portion of the St. Lawrence has its own characteristics and difficulties, the sector of navigation must be incorporated in the risk scenarios.

Each district (Montreal - Quebec City, Quebec City - Les Escoumins and Saguenay) was analysed to determine the level of difficulty of navigation. The determination was based on marine charts, navigation simulations and pilot comments during the three trips described in section 2.3.

The level of difficulty was related to the width, depth and sinuosity of the channel as well as the traffic (including pleasure boats). Thus the sector between Montreal and Quebec City is deemed to be difficult to navigate over 83% of its length, while the sector between Quebec City and Les Escoumins (including the Saguenay) is considered difficult over 48% of its length.

This difficulty factor is used in the model to determine the probability that the chain of events will occur in a hard-to-navigate location, thus making the situation worse.

## 6.2 Using the model

PRMM calls for the use of scenarios to evaluate risk levels associated with navigation between Montreal and Les Escoumins or navigation on the Saguenay. In order to be able to identify the circumstances under which the risk justifies the use of a second pilot or other mitigation measure, our model makes it easy to change the parameters so as to determine their impact on risk.

As mentioned at the beginning of this chapter, the model evaluates the probability of occurrence of a scenario by taking into consideration:

- sector of navigation;
- ship type and manoeuvrability;
- ship size;
- transit duration;
- presence or absence of a second pilot on board;
- various aggravating factors.

Each of these parameters can be changed, and the resulting variations in risk level determined, as well as any trends. Also, since the model simultaneously calculates the risk of a scenario with one pilot, two pilots and one pilot plus other mitigation measures, the effects of changing the contribution made by the second pilot/mitigation factor are easily identified.

The model is flexible enough that it can be used to analyse not only the defined scenarios but an indefinite number of situations.

To provide a comprehensive comparison of the scenarios, the model was used as follows:

- the risk level associated with each of the initial errors was calculated for a given ship transiting a given sector of navigation under the same navigating conditions;
- the average of the risk levels was calculated for the assumption that 1) the ship would dock at the end of the trip, and that 2) the ship would not dock at the end of the trip;
- the risk level was calculated for transits varying between 1 and 18 hours.

This approach yields, for one complete journey, with or without docking, the level of risk due to any given initial error, depending on the length of the trip. The results are given in chapter 7.

# 7. Results

This part of the report provides model outputs in various forms in order to demonstrate how the model performs. In order to analyse the outputs and draw conclusions, it is important to have a good understanding of the model's components and their interactions. The first two sections of the chapter are devoted to this matter.

## 7.1 Scenario versus transit

In order to meet the requirements of the Pilotage Risk Management Methodology (PRMM), the model was designed to evaluate the frequency and consequences of a scenario in order to obtain a level of risk for a specific incident arising from a series of events. The chain of events leading to the incident constitutes the scenario.

The scenarios used here, taken together, provide a good coverage of the double pilotage issue, representing as they do a set of situations that may occur during a complete transit between two points. To comply with PRMM, the scenarios had to be developed individually. The result is that individual situations are analysed and their associated risk evaluated. However, to determine whether a second pilot is necessary during a transit, we need to consider not an individual situation but a set of situations that may occur during a transit.

When developing the scenarios, we considered the possibility of linking them in order to provide an overall representation of a transit. This is indeed possible, and the model can then be used to yield risk levels applicable to a transit. The risk level for a transit is based on the weighted risks of all the individual scenarios.

Note that one of the scenarios concerns docking manoeuvres. This scenario is used only when a transit includes docking.

## 7.2 Selection of inputs

The inputs fall into three groups: those defining the scenario itself, the mitigation measures, and the aggravating factors. The inputs defining the scenario itself were selected to be as representative as possible of the realities encountered during a transit. The inputs related to mitigation measures and aggravating factors were selected on the basis of the consultations with stakeholders.

### 7.2.1 *Scenario defining inputs*

There are four kinds of scenario-defining inputs, namely those related to:

A basic scenarios;
B sector;
C ship;
D duration.

#### A. Basic scenarios

Following are the basic scenarios:

- pilot gives wrong order;
- helmsman errs in executing order;
- pilot misjudges ship's position;
- pilot misjudges navigating conditions;
- pilot misjudges speed or angle of approach when docking.

The scenarios are taken one at a time. To obtain the risk level for an entire transit, the weighted average of the scenarios is used. Appendix 5 presents each scenario in detail.

#### B. Sector

The sectors are considered in the same way regardless of whether the ship is moving upstream or downstream. The risk evaluation of a transit takes into consideration only one sector. The sectors are:

- Les Escoumins – Quebec City
- Les Escoumins – Saguenay
- Quebec City – Trois-Rivières
- Trois-Rivières – Montreal

## C. Ship

There are three ship-related inputs:

- ship type;
- manoeuvrability;
- length between perpendiculars.

Ship type is the most important of these inputs from the point of view of consequences. The second input is a factor characterizing the ship's manoeuvrability: when it is equal to 1, the ship has average manoeuvrability for its length; if it is greater than 1, manoeuvrability is low for the ship's length; if it less than 1, manoeuvrability is high. For purposes of our model, we selected ship types that are representative of current traffic on the St. Lawrence River. Appendix 6 sets out the procedure for evaluating ship manoeuvrability.

Since the length between perpendiculars is the most important variable with respect to the ship's ability to manoeuvre, it was selected over other ways of characterizing a ship's size. When using the model, this variable appears as a separate choice to be made.

The following ships are available in the model:

- oil tanker with manoeuvrability factor of 0.7133;
- oil tanker with manoeuvrability factor of 1;
- oil tanker with manoeuvrability factor of 1.5322;
- container ship with manoeuvrability factor of 0.8727;
- container ship with manoeuvrability factor of 1.279;
- bulker with manoeuvrability factor of 1.033;
- cargo ship with manoeuvrability factor of 0.9775;
- ro-ro with manoeuvrability factor of 0.8588;
- passenger ship with manoeuvrability factor of 1.

#### D. *Duration*

Transit duration is very important because the scenarios are based on an analysis of human factors, and these are directly related to fatigue. Thus a transit time must always be selected: any number of hours from 1 to 17.

### *7.2.2 Mitigation measures*

Mitigation measures are selected one at a time, except for the measure involving a second pilot. Since the present study is specifically concerned with the contribution of a second pilot, this is calculated independently each time the model is run. The other mitigation measures are considered one at a time to avoid obtaining the combined effect that would result if more than one measure were selected at a time. This is a weakness in the current version of the model, which could be corrected in a subsequent version. The model allows the user to select the following measures:

- re-arranged wheelhouse;
- better navigational aid system;
- more manœuvrable ship;
- more frequent change of pilot;
- better resource management on the bridge;
- experienced helmsman;
- up-to-date integrated electronic navigation system suited to conditions on the St. Lawrence.

### *7.2.3 Aggravating factors*

Unlike the mitigation measures, the aggravating factors can be processed several at a time. The factors used in the model are based on the consultations with the stakeholders. Once again, since the model works in terms of individual scenarios, in order to evaluate an entire transit, certain aggravating factors have to be selected even if they are encountered during only a portion of a transit. Following are the aggravating factors:

- ice conditions affecting navigation;
- seriously reduced visibility;
- high winds;
- night navigation (22:00 to 08:00);
- ship's characteristics and capabilities;

- crew's characteristics and capabilities (communication, experience, training, etc.) ;
- traffic density;
- defect or gap in normal navigational aid system;
- sinuous channel;
- width of channel
- currents;
- position and configuration of wheelhouse;
- general condition of ship;
- external constraints.

## 7.3 Model outputs

As our risk analysis model focuses on the human factor, the model outputs are organized in tables that plot transit duration against mitigating measures. Each output is calculated from a set of selected factors. Given the complexity of the model, there is no way to establish linear or proportional relationships between two outputs. Analysis must therefore be performed on a set of outputs that is as large as the number of variables involved in the risk evaluation. In the analysis as in the calculations, the Quebec City – Trois-Rivières sector and the Trois-Rivières – Montreal sector are deemed equivalent. The same applies to the Escoumins – Quebec City and Escoumins – Saguenay sectors.

The outputs are numerical. For the reader to grasp the significance of the numbers, it is important to understand that the results are on a scale of 0 to 30. A nil risk, corresponding to a nil probability or a nil consequence, is represented by 0, while maximum risk (probability of 1, or 100%) is represented by 30.

The following results are presented:

1. Comparison of sectors by transit duration, mitigation measures, and day versus night navigation;
2. Comparison of sectors by duration and ship length;
3. Comparison of sectors by environmental conditions;
4. Risk for different ship types;
5. Risk related to docking;
6. Risk with mitigation measures.

### *7.3.1 Comparison of sectors by transit duration, mitigation measures, and day versus night*

This output assumes a 230-foot cargo ship and normal summer daytime navigating conditions. Results are given for two mitigation measures: a second pilot and bridge resource management (BRM) as it should be practised under ideal conditions.

Table 12 – Results by duration for two sectors and daytime navigation

Trois-Rivières – Quebec City
Cargo, 230 m, day, summer

| *No docking* | | | |
|---|---|---|---|
| *Hours* | *1 pilot* | *2 pilots* | *BRM* |
| 1 | 0.0035 | 0.0014 | 0.0018 |
| 2 | 0.0035 | 0.0014 | 0.0018 |
| 3 | 0.0036 | 0.0014 | 0.0018 |
| 4 | 0.0036 | 0.0014 | 0.0018 |
| 5 | 0.0036 | 0.0014 | 0.0018 |
| 6 | 0.0032 | 0.0014 | 0.0017 |
| 7 | 0.0029 | 0.0014 | 0.0016 |
| 8 | 0.0032 | 0.0014 | 0.0017 |
| 9 | 0.0036 | 0.0014 | 0.0018 |
| 10 | 0.0043 | 0.0015 | 0.0020 |
| 11 | 0.0050 | 0.0016 | 0.0022 |
| 12 | 0.0059 | 0.0017 | 0.0024 |
| 13 | 0.0067 | 0.0017 | 0.0026 |
| 14 | 0.0080 | 0.0019 | 0.0029 |
| 15 | 0.0094 | 0.0020 | 0.0032 |
| 16 | 0.0111 | 0.0021 | 0.0036 |
| 17 | 0.0130 | 0.0022 | 0.0039 |
| 18 | 0.0150 | 0.0024 | 0.0043 |

Escoumins – Quebec City
Cargo, 230 m, day, summer

| *No docking* | | | |
|---|---|---|---|
| *Hours* | *1 pilot* | *2 pilots* | *BRM* |
| 1 | 0.0019 | 0.0008 | 0.0010 |
| 2 | 0.0019 | 0.0008 | 0.0010 |
| 3 | 0.0019 | 0.0008 | 0.0010 |
| 4 | 0.0019 | 0.0008 | 0.0010 |
| 5 | 0.0019 | 0.0008 | 0.0010 |
| 6 | 0.0017 | 0.0008 | 0.0009 |
| 7 | 0.0015 | 0.0007 | 0.0009 |
| 8 | 0.0017 | 0.0008 | 0.0009 |
| 9 | 0.0019 | 0.0008 | 0.0010 |
| 10 | 0.0023 | 0.0008 | 0.0011 |
| 11 | 0.0027 | 0.0009 | 0.0012 |
| 12 | 0.0032 | 0.0009 | 0.0013 |
| 13 | 0.0036 | 0.0009 | 0.0014 |
| 14 | 0.0043 | 0.0010 | 0.0016 |
| 15 | 0.0051 | 0.0011 | 0.0017 |
| 16 | 0.0060 | 0.0011 | 0.0019 |
| 17 | 0.0071 | 0.0012 | 0.0021 |
| 18 | 0.0081 | 0.0013 | 0.0023 |

Under the given circumstances, we see that a transit with a single pilot in the Trois-Rivières - Quebec City sector lasting 9 hours has a risk level of 0.0036, the same result that is obtained for a 13-hour transit in the Escoumins – Quebec City sector. However, it would be difficult to complete such a 13-hour transit during the day, so the figure of 0.0036 underestimates the risk since night navigation incurs a higher level of risk.

It can also be seen from Table 12 that double pilotage is more effective than bridge resource management. This can be explained by the fact that, regardless of the work done by the crew, the two pilots apply an effort management strategy. Also, each of them has local knowledge, so that when an unforeseeable event occurs, the reaction time is less than that of the crew even if the crew applies the principles of bridge resource management in optimal fashion.

Now let's look at the same situation, but with navigation at night instead of during the day. During nighttime navigating, there is a fatigue factor arising from the Circadian rhythm (in particular between 22:00 and 08:00). Also, visual acuity is diminished as a result of the change in lighting, and therefore objects are harder to discern. Table 13 shows the results.

As can be seen, the risk level for a nighttime transit with a single pilot is the same for 9 hours in the Trois-Rivières – Quebec City sector (0.0048) and for less than 12 hours in the Escoumins – Quebec City sector (0.0049 for 12 hours).

Table 13 – Results by duration for two sectors and nighttime navigation

Trois-Rivières – Quebec City
Cargo, 230 m summer, night

| *No docking* | | | |
|---|---|---|---|
| *Hours* | *1 pilot* | *2 pilots* | *BRM* |
| 1 | 0.0047 | 0.0015 | 0.0020 |
| 2 | 0.0047 | 0.0015 | 0.0020 |
| 3 | 0.0047 | 0.0015 | 0.0020 |
| 4 | 0.0048 | 0.0016 | 0.0020 |
| 5 | 0.0048 | 0.0016 | 0.0020 |
| 6 | 0.0041 | 0.0015 | 0.0019 |
| 7 | 0.0035 | 0.0014 | 0.0017 |
| 8 | 0.0041 | 0.0015 | 0.0019 |
| 9 | 0.0048 | 0.0016 | 0.0020 |
| 10 | 0.0060 | 0.0017 | 0.0023 |
| 11 | 0.0074 | 0.0018 | 0.0026 |
| 12 | 0.0090 | 0.0019 | 0.0029 |
| 13 | 0.0108 | 0.0020 | 0.0032 |
| 14 | 0.0134 | 0.0021 | 0.0036 |
| 15 | 0.0163 | 0.0023 | 0.0041 |
| 16 | 0.0200 | 0.0025 | 0.0046 |
| 17 | 0.0241 | 0.0027 | 0.0052 |
| 18 | 0.0285 | 0.0029 | 0.0058 |

Esccumins – Quebec City
Cargo, 230 m summer, night

| *No docking* | | | |
|---|---|---|---|
| *Hours* | *1 pilot* | *2 pilots* | *BRM* |
| 1 | 0.0025 | 0.0008 | 0.0011 |
| 2 | 0.0025 | 0.0008 | 0.0011 |
| 3 | 0.0026 | 0.0008 | 0.0011 |
| 4 | 0.0026 | 0.0008 | 0.0011 |
| 5 | 0.0026 | 0.0008 | 0.0011 |
| 6 | 0.0022 | 0.0008 | 0.0010 |
| 7 | 0.0019 | 0.0008 | 0.0009 |
| 8 | 0.0022 | 0.0008 | 0.0010 |
| 9 | 0.0026 | 0.0008 | 0.0011 |
| 10 | 0.0033 | 0.0009 | 0.0012 |
| 11 | 0.0040 | 0.0009 | 0.0014 |
| 12 | 0.0049 | 0.0010 | 0.0015 |
| 13 | 0.0059 | 0.0011 | 0.0017 |
| 14 | 0.0073 | 0.0012 | 0.0019 |
| 15 | 0.0089 | 0.0012 | 0.0022 |
| 16 | 0.0110 | 0.0013 | 0.0025 |
| 17 | 0.0132 | 0.0014 | 0.0028 |
| 18 | 0.0157 | 0.0015 | 0.0031 |

### *7.3.2 Comparison of sectors by transit duration and ship length*

As mentioned in chapter 6 (see also Appendix 6), length is the ship size parameter that best correlates with manoeuvrability. It is possible to use the model to determine the risk represented by the ship's length, all other factors being equal.

Table 14 charts the impact of length against transit duration. As in the previous section, the results are for a cargo ship operating under normal summer nighttime conditions. The increase in risk attributable to length and to transit duration can be seen.

## Table 14 – Results for two sectors by duration and ship length

Trois-Rivières – Quebec City
Cargo, night, summer

| Hours | Length | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 80 | 110 | 140 | 170 | 200 | 230 | 260 | 290 |
| 1 | 0.0025 | 0.0028 | 0.0032 | 0.0036 | 0.0041 | 0.0047 | 0.0053 | 0.0060 |
| 2 | 0.0025 | 0.0028 | 0.0032 | 0.0036 | 0.0041 | 0.0047 | 0.0053 | 0.0060 |
| 3 | 0.0025 | 0.0028 | 0.0032 | 0.0037 | 0.0042 | 0.0047 | 0.0054 | 0.0061 |
| 4 | 0.0025 | 0.0029 | 0.0033 | 0.0037 | 0.0042 | 0.0048 | 0.0054 | 0.0061 |
| 5 | 0.0025 | 0.0029 | 0.0033 | 0.0037 | 0.0042 | 0.0048 | 0.0054 | 0.0062 |
| 6 | 0.0022 | 0.0025 | 0.0029 | 0.0032 | 0.0037 | 0.0041 | 0.0047 | 0.0053 |
| 7 | 0.0019 | 0.0022 | 0.0025 | 0.0028 | 0.0031 | 0.0035 | 0.0040 | 0.0044 |
| 8 | 0.0022 | 0.0025 | 0.0029 | 0.0032 | 0.0037 | 0.0041 | 0.0047 | 0.0053 |
| 9 | 0.0025 | 0.0029 | 0.0033 | 0.0037 | 0.0042 | 0.0048 | 0.0054 | 0.0062 |
| 10 | 0.0031 | 0.0035 | 0.0041 | 0.0046 | 0.0053 | 0.0060 | 0.0069 | 0.0079 |
| 11 | 0.0037 | 0.0042 | 0.0049 | 0.0056 | 0.0064 | 0.0074 | 0.0085 | 0.0097 |
| 12 | 0.0044 | 0.0051 | 0.0059 | 0.0068 | 0.0078 | 0.0090 | 0.0104 | 0.0120 |
| 13 | 0.0051 | 0.0059 | 0.0069 | 0.0080 | 0.0093 | 0.0108 | 0.0125 | 0.0144 |
| 14 | 0.0061 | 0.0072 | 0.0084 | 0.0098 | 0.0115 | 0.0134 | 0.0156 | 0.0181 |
| 15 | 0.0073 | 0.0086 | 0.0101 | 0.0118 | 0.0139 | 0.0163 | 0.0190 | 0.0222 |
| 16 | 0.0087 | 0.0103 | 0.0122 | 0.0144 | 0.0170 | 0.0200 | 0.0235 | 0.0275 |
| 17 | 0.0102 | 0.0122 | 0.0145 | 0.0172 | 0.0204 | 0.0241 | 0.0284 | 0.0334 |

Table 14 – Results for two sectors by duration and ship length (continued)

Escoumins – Quebec City
Cargo, night, summer

| *Hours* | *Length* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *80* | *110* | *140* | *170* | *200* | *230* | *260* | *290* |
| 1 | 0.0013 | 0.0015 | 0.0017 | 0.0020 | 0.0022 | 0.0025 | 0.0029 | 0.0033 |
| 2 | 0.0013 | 0.0015 | 0.0017 | 0.0020 | 0.0022 | 0.0025 | 0.0029 | 0.0033 |
| 3 | 0.0013 | 0.0015 | 0.0017 | 0.0020 | 0.0023 | 0.0026 | 0.0029 | 0.0033 |
| 4 | 0.0014 | 0.0015 | 0.0018 | 0.0020 | 0.0023 | 0.0026 | 0.0029 | 0.0033 |
| 5 | 0.0014 | 0.0016 | 0.0018 | 0.0020 | 0.0023 | 0.0026 | 0.0030 | 0.0034 |
| 6 | 0.0012 | 0.0014 | 0.0015 | 0.0017 | 0.0020 | 0.0022 | 0.0025 | 0.0029 |
| 7 | 0.0010 | 0.0012 | 0.0013 | 0.0015 | 0.0017 | 0.0019 | 0.0021 | 0.0024 |
| 8 | 0.0012 | 0.0014 | 0.0015 | 0.0017 | 0.0020 | 0.0022 | 0.0025 | 0.0029 |
| 9 | 0.0014 | 0.0016 | 0.0018 | 0.0020 | 0.0023 | 0.0026 | 0.0030 | 0.0034 |
| 10 | 0.0017 | 0.0019 | 0.0022 | 0.0025 | 0.0029 | 0.0033 | 0.0038 | 0.0043 |
| 11 | 0.0020 | 0.0023 | 0.0026 | 0.0030 | 0.0035 | 0.0040 | 0.0046 | 0.0053 |
| 12 | 0.0024 | 0.0027 | 0.0032 | 0.0037 | 0.0043 | 0.0049 | 0.0057 | 0.0066 |
| 13 | 0.0028 | 0.0032 | 0.0037 | 0.0044 | 0.0051 | 0.0059 | 0.0068 | 0.0079 |
| 14 | 0.0033 | 0.0039 | 0.0046 | 0.0054 | 0.0063 | 0.0073 | 0.0085 | 0.0099 |
| 15 | 0.0039 | 0.0046 | 0.0055 | 0.0065 | 0.0076 | 0.0089 | 0.0104 | 0.0122 |
| 16 | 0.0047 | 0.0056 | 0.0066 | 0.0079 | 0.0093 | 0.0110 | 0.0129 | 0.0151 |
| 17 | 0.0055 | 0.0066 | 0.0079 | 0.0094 | 0.0112 | 0.0132 | 0.0156 | 0.0184 |

### 7.3.3 *Comparison of sectors by environmental conditions*

Table 15 compares the same ship operating under good conditions in two sectors, assuming a similar degree of difficulty. It charts aggravating factors in the form of environmental conditions against mitigating measures.

Table 15 – Results for two sectors by environmental conditions

Trois-Rivières – Quebec City (8 hours)
Cargo, 230 m, day, summer

| *Aggravating factor* | *1 pilot* | *2 pilots* | *BRM* |
|---|---|---|---|
| Normal | 0.0032 | 0.0014 | 0.0017 |
| Night | 0.0041 | 0.0015 | 0.0019 |
| Aids removed | 0.0045 | 0.0015 | 0.0019 |
| Ice + aids removed | 0.0056 | 0.0016 | 0.0021 |
| Fog or snow | 0.0055 | 0.0016 | 0.0021 |
| Traffic density | 0.0043 | 0.0015 | 0.0020 |

Escoumins – Quebec City (11 hours)
Cargo, 230 m, day, summer

| *Aggravating factor* | *1 pilot* | *2 pilots* | *BRM* |
|---|---|---|---|
| Normal | 0.0027 | 0.0009 | 0.0012 |
| Night | 0.0040 | 0.0009 | 0.0014 |
| Aids removed | 0.0042 | 0.0009 | 0.0014 |
| Ice + aids removed | 0.0059 | 0.0010 | 0.0016 |
| Fog or snow | 0.0056 | 0.0010 | 0.0016 |
| Traffic density | 0.0040 | 0.0010 | 0.0015 |

Table 15 shows that the model can evaluate the impact on risk of a change in season. This can be seen in the increased risk due to removal of aids and to the presence of ice.

It is also possible to analyse environmental conditions against transit duration, yielding tables such as Table 16.

Table 16 – Results for two sectors by environmental conditions and transit duration

Trois-Rivières – Quebec City
Cargo, 230 m

| *Hours* | *Day* | *Night* | *Buoys removed* | *Buoys removed + Ice* | *Buoys removed + Ice + Night* |
|---|---|---|---|---|---|
| 1 | 0.0035 | 0.0047 | 0.0050 | 0.0064 | 0.0091 |
| 2 | 0.0035 | 0.0047 | 0.0050 | 0.0065 | 0.0092 |
| 3 | 0.0036 | 0.0047 | 0.0050 | 0.0065 | 0.0093 |
| 4 | 0.0036 | 0.0048 | 0.0051 | 0.0066 | 0.0094 |
| 5 | 0.0036 | 0.0048 | 0.0051 | 0.0067 | 0.0095 |
| 6 | 0.0032 | 0.0041 | 0.0045 | 0.0056 | 0.0077 |
| 7 | 0.0029 | 0.0035 | 0.0038 | 0.0047 | 0.0061 |
| 8 | 0.0032 | 0.0041 | 0.0045 | 0.0056 | 0.0077 |
| 9 | 0.0036 | 0.0048 | 0.0051 | 0.0067 | 0.0095 |
| 10 | 0.0043 | 0.0060 | 0.0063 | 0.0086 | 0.0130 |
| 11 | 0.0050 | 0.0074 | 0.0077 | 0.0108 | 0.0170 |
| 12 | 0.0059 | 0.0090 | 0.0092 | 0.0134 | 0.0220 |
| 13 | 0.0067 | 0.0108 | 0.0109 | 0.0164 | 0.0276 |
| 14 | 0.0080 | 0.0134 | 0.0134 | 0.0208 | 0.0362 |
| 15 | 0.0094 | 0.0163 | 0.0162 | 0.0257 | 0.0460 |
| 16 | 0.0111 | 0.0200 | 0.0197 | 0.0321 | 0.0590 |
| 17 | 0.0130 | 0.0241 | 0.0236 | 0.0392 | 0.0736 |
| 18 | 0.0150 | 0.0285 | 0.0278 | 0.0470 | 0.0898 |

Escoumins – Quebec City
Cargo, 230 m

| *Hours* | *Day* | *Night* | *Buoys removed* | *Buoys removed + Ice* | *Buoys removed + Ice + Night* |
|---|---|---|---|---|---|
| 1 | 0.0019 | 0.0025 | 0.0027 | 0.0035 | 0.0050 |
| 2 | 0.0019 | 0.0025 | 0.0027 | 0.0035 | 0.0051 |
| 3 | 0.0019 | 0.0026 | 0.0027 | 0.0036 | 0.0051 |
| 4 | 0.0019 | 0.0026 | 0.0028 | 0.0036 | 0.0052 |
| 5 | 0.0019 | 0.0026 | 0.0028 | 0.0036 | 0.0052 |
| 6 | 0.0017 | 0.0022 | 0.0024 | 0.0031 | 0.0042 |
| 7 | 0.0015 | 0.0019 | 0.0021 | 0.0025 | 0.0034 |
| 8 | 0.0017 | 0.0022 | 0.0024 | 0.0031 | 0.0042 |
| 9 | 0.0019 | 0.0026 | 0.0028 | 0.0036 | 0.0052 |
| 10 | 0.0023 | 0.0033 | 0.0034 | 0.0047 | 0.0072 |
| 11 | 0.0027 | 0.0040 | 0.0042 | 0.0059 | 0.0094 |
| 12 | 0.0032 | 0.0049 | 0.0050 | 0.0074 | 0.0121 |
| 13 | 0.0036 | 0.0059 | 0.0060 | 0.0090 | 0.0153 |
| 14 | 0.0043 | 0.0073 | 0.0073 | 0.0114 | 0.0200 |
| 15 | 0.0051 | 0.0089 | 0.0089 | 0.0141 | 0.0255 |
| 16 | 0.0060 | 0.0110 | 0.0108 | 0.0177 | 0.0327 |
| 17 | 0.0071 | 0.0132 | 0.0129 | 0.0216 | 0.0407 |
| 18 | 0.0081 | 0.0157 | 0.0152 | 0.0259 | 0.0497 |

### *7.3.4 Risk for different ship types*

When calculating risk for a transit, it is important to bear in mind that risk depends on the frequency of an event and on its consequences. Frequency should be the same for similar ships of the same size and characteristics. However, the consequences of an event will vary with the type of ship.

Table 17 compares different types of ship having similar manoeuvrability and size and operating under the same environmental conditions. The different results obtained with cargo ships and oil tankers thus arise solely from the type of cargo. In this particular case, the difference in risk arises from the consequences of an incident. The probability of an incident is the same for both types of ship.

Table 17 – Risk analysis for different ship types

Trois-Rivières – Quebec City
230 m, summer, might, 1 pilot

| *Hours* | *Cargo* | *Oil tanker* | *Passenger* |
|---|---|---|---|
| 1 | 0.0047 | 0.0063 | 0.0096 |
| 2 | 0.0047 | 0.0063 | 0.0097 |
| 3 | 0.0047 | 0.0064 | 0.0098 |
| 4 | 0.0048 | 0.0064 | 0.0099 |
| 5 | 0.0048 | 0.0065 | 0.0100 |
| 6 | 0.0041 | 0.0056 | 0.0085 |
| 7 | 0.0035 | 0.0047 | 0.0071 |
| 8 | 0.0041 | 0.0056 | 0.0085 |
| 9 | 0.0048 | 0.0065 | 0.0100 |
| 10 | 0.0060 | 0.0082 | 0.0129 |
| 11 | 0.0074 | 0.0100 | 0.0161 |
| 12 | 0.0090 | 0.0122 | 0.0200 |
| 13 | 0.0108 | 0.0146 | 0.0242 |
| 14 | 0.0134 | 0.0182 | 0.0307 |
| 15 | 0.0163 | 0.0221 | 0.0378 |
| 16 | 0.0200 | 0.0272 | 0.0471 |
| 17 | 0.0241 | 0.0327 | 0.0575 |

Escoumins – Quebec City
230 m, summer, night, 1 pilot

| *Hours* | *Cargo* | *Oil tanker* | *Passenger* |
|---|---|---|---|
| 1 | 0.0025 | 0.0063 | 0.0062 |
| 2 | 0.0025 | 0.0063 | 0.0063 |
| 3 | 0.0026 | 0.0064 | 0.0063 |
| 4 | 0.0026 | 0.0064 | 0.0063 |
| 5 | 0.0026 | 0.0065 | 0.0064 |
| 6 | 0.0022 | 0.0056 | 0.0055 |
| 7 | 0.0019 | 0.0047 | 0.0047 |
| 8 | 0.0022 | 0.0056 | 0.0055 |
| 9 | 0.0026 | 0.0065 | 0.0064 |
| 10 | 0.0033 | 0.0082 | 0.0081 |
| 11 | 0.0040 | 0.0100 | 0.0100 |
| 12 | 0.0049 | 0.0122 | 0.0122 |
| 13 | 0.0059 | 0.0146 | 0.0146 |
| 14 | 0.0073 | 0.0182 | 0.0182 |
| 15 | 0.0089 | 0.0221 | 0.0222 |
| 16 | 0.0110 | 0.0272 | 0.0274 |
| 17 | 0.0132 | 0.0327 | 0.0331 |

In the case of the passenger ship, the wheelhouse configuration (located fore) was taken into consideration along with the consequences of an incident. Thus the result for risk reflects both these factors, not consequences only. The configuration of the wheelhouse affects the frequency of an event involving a passenger ship.

### *7.3.5 Risk related to docking*

The model can be used to evaluate the risk of a transit with a docking manoeuvre at the end (including total trip time). It is significant that docking takes place at the end of the transit, when the pilot may already have been working for many hours. Table 18 shows the risk related to docking.

Table 18 – Risk related to docking

Trois-Rivières – Quebec City
Cargo, 230 m, summer, night

| *Impact of docking with 1 pilot* | | |
|---|---|---|
| *Hours* | *Without docking* | *With docking* |
| 1 | 0.0047 | 0.0052 |
| 2 | 0.0047 | 0.0053 |
| 3 | 0.0047 | 0.0053 |
| 4 | 0.0048 | 0.0054 |
| 5 | 0.0048 | 0.0054 |
| 6 | 0.0041 | 0.0046 |
| 7 | 0.0035 | 0.0039 |
| 8 | 0.0041 | 0.0046 |
| 9 | 0.0048 | 0.0054 |
| 10 | 0.0060 | 0.0069 |
| 11 | 0.0074 | 0.0085 |
| 12 | 0.0090 | 0.0105 |
| 13 | 0.0108 | 0.0126 |
| 14 | 0.0134 | 0.0158 |
| 15 | 0.0163 | 0.0194 |
| 16 | 0.0200 | 0.0240 |
| 17 | 0.0241 | 0.0291 |
| 18 | 0.0285 | 0.0347 |

Escoumins – Quebec City
Cargo, 230 m, summer, night

| *Impact of docking with 1 pilot* | | |
|---|---|---|
| *Hours* | *Without docking* | *With docking* |
| 1 | 0.0025 | 0.0030 |
| 2 | 0.0025 | 0.0030 |
| 3 | 0.0026 | 0.0030 |
| 4 | 0.0026 | 0.0030 |
| 5 | 0.0026 | 0.0031 |
| 6 | 0.0022 | 0.0026 |
| 7 | 0.0019 | 0.0022 |
| 8 | 0.0022 | 0.0026 |
| 9 | 0.0026 | 0.0031 |
| 10 | 0.0033 | 0.0039 |
| 11 | 0.0040 | 0.0049 |
| 12 | 0.0049 | 0.0060 |
| 13 | 0.0059 | 0.0073 |
| 14 | 0.0073 | 0.0092 |
| 15 | 0.0089 | 0.0113 |
| 16 | 0.0110 | 0.0141 |
| 17 | 0.0132 | 0.0172 |
| 18 | 0.0157 | 0.0205 |

As can be seen, docking increases risk in a manner similar to an increase of one hour in the transit duration.

### *7.3.6 Risk with mitigation measures*

The model allows analysis of the risk involved when mitigation measures are in place. The measures in question were presented to stakeholders but not validated by them. Consequently, the results given here are for information only. Had the measures been validated, then the results obtained could have been used in formulating recommendations.

The model includes four mitigation measures:

- second pilot;
- bridge resource management;
- experienced helmsman who knows the language and the sector;
- integrated navigation system meeting international standards (ECDIS, S-57, etc.) and crew trained to use it.

Table 19 shows the impact on risk of using these measures.

Table 19 – Impact of mitigation measures on risk

Trois-Rivières – Quebec City
Cargo, 230 m, summer, day

| *Hours* | *1 pilot* | *2 pilots* | *BRM* | *Helmsman* | *Nav. Sys.* |
|---|---|---|---|---|---|
| 1 | 0.0035 | 0.0014 | 0.0018 | 0.0025 | 0.0022 |
| 2 | 0.0035 | 0.0014 | 0.0018 | 0.0025 | 0.0022 |
| 3 | 0.0036 | 0.0014 | 0.0018 | 0.0025 | 0.0022 |
| 4 | 0.0036 | 0.0014 | 0.0018 | 0.0025 | 0.0022 |
| 5 | 0.0036 | 0.0014 | 0.0018 | 0.0026 | 0.0023 |
| 6 | 0.0032 | 0.0014 | 0.0017 | 0.0023 | 0.0021 |
| 7 | 0.0029 | 0.0014 | 0.0016 | 0.0021 | 0.0019 |
| 8 | 0.0032 | 0.0014 | 0.0017 | 0.0023 | 0.0021 |
| 9 | 0.0036 | 0.0014 | 0.0018 | 0.0026 | 0.0023 |
| 10 | 0.0043 | 0.0015 | 0.0020 | 0.0029 | 0.0026 |
| 11 | 0.0050 | 0.0016 | 0.0022 | 0.0033 | 0.0029 |
| 12 | 0.0059 | 0.0017 | 0.0024 | 0.0037 | 0.0032 |
| 13 | 0.0067 | 0.0017 | 0.0026 | 0.0042 | 0.0036 |
| 14 | 0.0080 | 0.0019 | 0.0029 | 0.0048 | 0.0041 |
| 15 | 0.0094 | 0.0020 | 0.0032 | 0.0055 | 0.0046 |
| 16 | 0.0111 | 0.0021 | 0.0036 | 0.0063 | 0.0052 |
| 17 | 0.0130 | 0.0022 | 0.0039 | 0.0072 | 0.0059 |
| 18 | 0.0150 | 0.0024 | 0.0043 | 0.0081 | 0.0066 |

Table 19 – Impact of mitigation measures on risk (continued)

Escoumins – Quebec City
Cargo, 230 m, summer, day

| *Hours* | *1 pilot* | *2 pilots* | *BRM* | *Helmsman* | *Nav. Sys.* |
|---|---|---|---|---|---|
| 1 | 0.0019 | 0.0008 | 0.0010 | 0.0013 | 0.0012 |
| 2 | 0.0019 | 0.0008 | 0.0010 | 0.0014 | 0.0012 |
| 3 | 0.0019 | 0.0008 | 0.0010 | 0.0014 | 0.0012 |
| 4 | 0.0019 | 0.0008 | 0.0010 | 0.0014 | 0.0012 |
| 5 | 0.0019 | 0.0008 | 0.0010 | 0.0014 | 0.0012 |
| 6 | 0.0017 | 0.0008 | 0.0009 | 0.0013 | 0.0011 |
| 7 | 0.0015 | 0.0007 | 0.0009 | 0.0012 | 0.0010 |
| 8 | 0.0017 | 0.0008 | 0.0009 | 0.0013 | 0.0011 |
| 9 | 0.0019 | 0.0008 | 0.0010 | 0.0014 | 0.0012 |
| 10 | 0.0023 | 0.0008 | 0.0011 | 0.0016 | 0.0014 |
| 11 | 0.0027 | 0.0009 | 0.0012 | 0.0018 | 0.0015 |
| 12 | 0.0032 | 0.0009 | 0.0013 | 0.0020 | 0.0017 |
| 13 | 0.0036 | 0.0009 | 0.0014 | 0.0023 | 0.0019 |
| 14 | 0.0043 | 0.0010 | 0.0016 | 0.0026 | 0.0022 |
| 15 | 0.0051 | 0.0011 | 0.0017 | 0.0030 | 0.0025 |
| 16 | 0.0060 | 0.0011 | 0.0019 | 0.0034 | 0.0028 |
| 17 | 0.0071 | 0.0012 | 0.0021 | 0.0039 | 0.0032 |
| 18 | 0.0081 | 0.0013 | 0.0023 | 0.0044 | 0.0036 |

# 8. Conclusion

The main objective of this study was to:

> *"carry out a risk-based assessment to determine when and under which circumstances double pilotage should be obligatory in the Laurentian Pilotage Authority region, and to determine what the duties of the second pilot and/or pilotage certificate holder should be, if any".*

More specifically, the following questions were to be answered:

- What are the second pilot's duties?
- What is the added value of the second pilot?
- How much is risk reduced by having the second pilot?
- When is a second pilot really necessary?

In the sections that follow, these questions are answered in the light of the analyses made in the course of this study.

What are the second pilot's duties?

The risk we are trying to reduce by adding a second pilot is directly associated with the human factor. The second pilot's role is to reduce risk when the first pilot alone cannot pilot the ship safely. This occurs under certain circumstances, as indicated by our literature review, the consultations we made, the reconnaissance and validation trips, and the submissions that we received. A second pilot becomes a justifiable risk mitigation measure when:

- excessive fatigue is created by the conditions of an assignment, such as the time between the pilot's waking and embarking, the frequency of trips, and the duration of the transit;
- aggravating factors related to the ship or to environmental conditions increase the stress level, increase the quantity of information to be processed, make it harder to gather this information (e.g., poor bridge configuration or ice on windows), reduce the response time available to make a decision, or amplify the consequences of a wrong decision.

Under these circumstances, the second pilot contributes by relieving the first pilot when the latter is tired or by assisting with the collection and processing of information. The second pilot also helps monitor navigation of the ship and execution of orders by the helmsman. In the more difficult areas of District No. 2, the second pilot is on active watch while the first pilot looks after navigating the ship; during the rest of the transit, the second pilot is on passive watch. Passive watch is needed because trips are much longer than in District No. 1, and as a result the first pilot gets more tired and needs to be relieved. As for District No. 1, there are several factors that create difficulties along almost the entire length of a transit, such as the sinuosity of the river, the narrowness of the channel and the effects of the current. The second pilot is therefore on continuous active watch.

### What is the added value of the second pilot?

Double pilotage can be justified when the level of risk with a single pilot reaches or exceeds a certain threshold. A second pilot can bring the risk back below this established threshold by reducing the probability of occurrence of an event or by helping to reduce the consequences of an event. In some cases, however, adding a second pilot will not reduce the risk sufficiently, and additional mitigation measures will be needed (e.g., delay the transit and move the ship to an anchorage).

### How much is risk reduced by having the second pilot?

A second pilot is not always necessary and may not be sufficient to keep the risk below an acceptable threshold value. Still, as we have seen, it is justified under certain circumstances. The second pilot's contribution to reducing risk will vary with circumstances.

### When is a second pilot really necessary?

Having a second pilot is a justifiable mitigation measure if it can bring the risk down below an acceptable threshold. There can be no question of eliminating risk. Even with a second pilot, a degree of risk remains, as can be seen from the fact that accidents have occurred even when there are two pilots aboard. The question should be answered in terms of keeping the risk below a tolerable level. When there are two pilots aboard, different work methods are called for: there has to be clear division of tasks and responsibilities between the two pilots. Also, double pilotage practices in District 1 differ from those in District 2.

The level of risk can of course vary from one trip to another. The same ship making a transit under differing conditions (e.g., night rather than day, or winter rather than summer) will incur different risks. Ideally the risk should be established for each trip, and in fact this is made possible by the model developed for the present study. That risk would then be compared to an acceptable threshold value, beyond which a second pilot would be required, or else a comparable mitigation measure. Such a case-by-case approach would avoid setting rules based on a generalization, which inevitably creates unfairness (ships at risk are exempted from double pilotage while ships not exposed to any excessive risk are required to have a second pilot). Such an approach also has the advantage of being adaptable to changes in the navigation environment on the St. Lawrence River (e.g., the model could be modified to take into account new technologies, larger ships, etc.). Finally, with a case-by-case approach, the contribution of a second pilot can be compared to the contribution of other mitigation measures, and thus the best risk-reducing option can be chosen.

The disadvantage of a case-by-case approach is that it provides no guidelines for deciding in advance whether a second pilot will be required. That would mean uncertainty for the LPA as well as for pilots and shipowners, at least during the first years of using such an approach, though eventually it would be possible to identify certain situations where a second pilot is systematically required by the model and other situations where a second pilot is never required. In the remaining situations, there would continue to be uncertainty; a determination could not be made until the time of the transit.

In order to create regulations based on risk levels without imposing a case-by-case approach, we could run hypothetical transits through the model. However, in order to cover all possibilities, the model would have to be run tens of thousands of times, and processing of the results would have to be automated. The model was designed to provide results on a case-by-case basis; it cannot handle thousands of situations at once. We have therefore restricted our analysis to about 1 000 cases, with a focus on the requirements of the existing regulations to see whether such an approach is useful. To do more would exceed the limitations of this study. We also have yet to validate several aspects of the model, notably the mitigation measures other than a second pilot, and the aggravating factors.

There were three steps involved in using the model to review the double pilotage regulations:

1. Defining the acceptable level of risk
2. Calculating the level of risk for various situations, based on the requirements of the existing regulations.

3. Determining the circumstances under which the level of risk with a single pilot exceeds the acceptable threshold (thus reviewing the foundations of the regulations).

### 1. Defining the acceptable level of risk

We take an acceptable level of risk to be the risk we currently assume with ships that regularly sail the St. Lawrence River. We calculated risk for a ship that has characteristics similar to those of the Canadian fleet of bulk carriers and that is sailing under normal summer navigating conditions at night. Table 20 shows the results and forms the basis of our ceiling of acceptable risk, namely 0.0048. To arrive at this figure, we looked at the risk between Montreal and Trois-Rivières and between Trois-Rivières and Quebec City. As can be seen, the risk is already 0.0047 after just one hour. There is a drop in risk at the sixth, seventh and eighth hours, but at the ninth hour it is back near its initial level, at 0.0048. This threshold level thus corresponds to a nighttime transit of 9 hours between Montreal and Trois-Rivières or between Trois-Rivières and Quebec City, or a transit of over 11 hours between Les Escoumins and Quebec City. The daytime equivalent would be 11 hours or less between Montreal and Trois-Rivières or between Trois-Rivières and Quebec City, or less than 15 hours between Les Escoumins and Quebec City. However, it would be hard to complete transits of 11 or 15 hours entirely during the daytime. That is why we set our threshold on the basis of a nighttime transit.

Our model assigns a value between 0 and 30 to risk, depending on the probability of occurrence, the severity of consequences and the particular parameters selected. A ceiling of 0.0048 represents very low risk and is in our view acceptable. Obviously others may decide that a higher or lower value would be better. It all depends on the risk one is prepared to assume, knowing that risk cannot be eliminated.

The threshold beyond which a second pilot would be required (or some other mitigation measure having similar impact) is thus defined in terms of maximum risk (0.0048) and transit duration (11 hours between Les Escoumins and Quebec City, including the Saguenay; 9 hours between Quebec City and Trois-Rivières or between Trois-Rivières and Montreal).

### 2. Calculating the level of risk for various situations, based on the requirements of the existing regulations

We used the model to calculate risk for the conditions that form the basis of the existing double pilotage regulations. We also looked at other cases to determine the effect of moving away from the prescribed conditions. We restricted ourselves to the following situations:

1. Two pilotage areas:
   1.1 Les Escoumins – Quebec City, including the Saguenay
   1.2 Quebec City – Trois-Rivières or Trois-Rivières – Montreal
2. Three ship types:
   2.1 Freighters other than tankers
   2.2 Tankers
   2.3 Passenger ships
3. Ship length: from 80 m to 290 m by 30-m increments (i.e., eight different sizes)
4. Navigating period: summer
5. Transit duration: between 1 and 17 hours (i.e., 17 different durations)
6. Time of trip: nighttime transit (note that a transit is deemed to be a daytime transit only if it takes place entirely during daylight hours. Any transit that takes place even partially during the hours of darkness is a nighttime transit)
7. Special condition: no docking

Combining these parameters, we obtain 816 different situations distributed over the following six categories:

1. Quebec City – Trois-Rivières or Trois-Rivières – Montreal, freighter (other than tanker), nighttime, summer.
2. Les Escoumins – Quebec City (including the Saguenay), freighter (other than tanker), nighttime, summer.
3. Quebec City – Trois-Rivières or Trois-Rivières – Montreal, tanker, nighttime, summer.
4. Les Escoumins – Quebec City (including the Saguenay), tanker, nighttime, summer.
5. Quebec City – Trois-Rivières or Trois-Rivières – Montreal, passenger ship, nighttime, summer.
6. Les Escoumins – Quebec City (including the Saguenay), passenger ship, nighttime, summer.

Tables 20 to 25 set out the risks for these six categories, for various ship sizes and transit durations, on the assumption of normal navigating conditions, average manoeuvrability and a typical crew.

3. Determining the circumstances under which the level of risk with a single pilot exceeds the acceptable threshold.

Chapter 7 presented the results of applying the model to the conditions prescribed by the regulations. The indicator used for ship size was length rather than tonnage. Length has a direct impact on manoeuvrability and provides a better indicator of the ease with which a ship can be piloted. Another factor to be taken into account is the transit duration, since this has a direct effect on fatigue. This is why the results in Tables 20-25 are given in terms of ship length and transit duration. Results are given for each pilotage district for freighters, tankers and passenger ships navigating at night in summer.

Table 20 – Risks for freighter (other than tanker) at night in summer in District 1, by ship length and transit duration

| *Hours/Length* | *80* | *110* | *140* | *170* | *200* | *230* | *260* | *290* |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.0025 | 0.0028 | 0.0032 | 0.0036 | 0.0041 | 0.0047 | 0.0053 | 0.0060 |
| 2 | 0.0025 | 0.0028 | 0.0032 | 0.0036 | 0.0041 | 0.0047 | 0.0053 | 0.0060 |
| 3 | 0.0025 | 0.0028 | 0.0032 | 0.0037 | 0.0042 | 0.0047 | 0.0054 | 0.0061 |
| 4 | 0.0025 | 0.0029 | 0.0033 | 0.0037 | 0.0042 | 0.0048 | 0.0054 | 0.0061 |
| 5 | 0.0025 | 0.0029 | 0.0033 | 0.0037 | 0.0042 | 0.0048 | 0.0054 | 0.0062 |
| 6 | 0.0022 | 0.0025 | 0.0029 | 0..032 | 0.0037 | 0.0041 | 0.0047 | 0.0053 |
| 7 | 0.0019 | 0.0022 | 0.0025 | 0.0028 | 0.0031 | 0.0035 | 0.0040 | 0.0044 |
| 8 | 0.0022 | 0.0025 | 0.0029 | 0.0032 | 0.0037 | 0.0041 | 0.0047 | 0.0053 |
| 9 | 0.0025 | 0.0029 | 0.0033 | 0.0037 | 0.0042 | 0.0048 | 0.0054 | 0.0062 |
| 10 | 0.0031 | 0.0035 | 0.0041 | 0.0046 | 0.0053 | 0.0060 | 0.0069 | 0.0079 |
| 11 | 0.0037 | 0.0042 | 0.0049 | 0.0056 | 0.0064 | 0.0074 | 0.0085 | 0.0097 |
| 12 | 0.0044 | 0.0051 | 0.0059 | 0.0068 | 0.0078 | 0.0090 | 0.0104 | 0.0120 |
| 13 | 0.0051 | 0.0059 | 0.0069 | 0.0080 | 0.0093 | 0.0108 | 0.0125 | 0.0144 |
| 14 | 0.0061 | 0.0072 | 0.0084 | 0.0098 | 0.0115 | 0.0134 | 0.0156 | 0.0181 |
| 15 | 0.0073 | 0.0086 | 0.0101 | 0.0118 | 0.0139 | 0.0163 | 0.0190 | 0.0222 |
| 16 | 0.0087 | 0.0103 | 0.0122 | 0.0144 | 0.0170 | 0.0200 | 0.0235 | 0.0275 |
| 17 | 0.0102 | 0.0122 | 0.0145 | 0.0172 | 0.0204 | 0.0241 | 0.0284 | 0.0334 |

Table 21 – Risks for freighter (other than tanker) at night in summer in District 2, by ship length and transit duration

| *Hours/Length* | *80* | *110* | *140* | *170* | *200* | *230* | *260* | *290* |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.0013 | 0.0015 | 0.0017 | 0.0020 | 0.0022 | 0.0025 | 0.0029 | 0.0033 |
| 2 | 0.0013 | 0.0015 | 0.0017 | 0.0020 | 0.0022 | 0.0025 | 0.0029 | 0.0033 |
| 3 | 0.0013 | 0.0015 | 0.0017 | 0.0020 | 0.0023 | 0.0026 | 0.0029 | 0.0033 |
| 4 | 0.0014 | 0.0015 | 0.0018 | 0.0020 | 0.0023 | 0.0026 | 0.0029 | 0.0033 |
| 5 | 0.0014 | 0.0016 | 0.0018 | 0.0020 | 0.0023 | 0.0026 | 0.0030 | 0.0034 |
| 6 | 0.0012 | 0.0014 | 0.0015 | 0.0017 | 0.0020 | 0.0022 | 0.0025 | 0.0029 |
| 7 | 0.0010 | 0.0012 | 0.0013 | 0.0015 | 0.0017 | 0.0019 | 0.0021 | 0.0024 |
| 8 | 0.0012 | 0.0014 | 0.0015 | 0.0017 | 0.0020 | 0.0022 | 0.0025 | 0.0029 |
| 9 | 0.0014 | 0.0016 | 0.0018 | 0.0020 | 0.0023 | 0.0026 | 0.0030 | 0.0034 |
| 10 | 0.0017 | 0.0019 | 0.0022 | 0.0025 | 0.0029 | 0.0033 | 0.0038 | 0.0043 |
| 11 | 0.0020 | 0.0023 | 0.0026 | 0.0030 | 0.0035 | 0.0040 | 0.0046 | 0.0053 |
| 12 | 0.0024 | 0.0027 | 0.0032 | 0.0037 | 0.0043 | 0.0049 | 0.0057 | 0.0066 |
| 13 | 0.0028 | 0.0032 | 0.0037 | 0.0044 | 0.0051 | 0.0059 | 0.0068 | 0.0079 |
| 14 | 0.0033 | 0.0039 | 0.0046 | 0.0054 | 0.0063 | 0.0073 | 0.0085 | 0.0099 |
| 15 | 0.0039 | 0.0046 | 0.0055 | 0.0065 | 0.0076 | 0.0089 | 0.0104 | 0.0122 |
| 16 | 0.0047 | 0.0056 | 0.0066 | 0.0079 | 0.0093 | 0.0110 | 0.0129 | 0.0151 |
| 17 | 0.0055 | 0.0066 | 0.0079 | 0.0094 | 0.0112 | 0.0132 | 0.0156 | 0.0184 |

Table 22 – Risks for passenger ship at night in summer in District 1, by ship length and transit duration

| *Hours/Length* | *80* | *110* | *140* | *170* | *200* | *230* | *260* | *290* |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.0045 | 0.0053 | 0.0061 | 0.0071 | 0.0083 | 0.0096 | 0.0112 | 0.0130 |
| 2 | 0.0046 | 0.0053 | 0.0062 | 0.0072 | 0.0084 | 0.0097 | 0.0113 | 0.0131 |
| 3 | 0.0046 | 0.0053 | 0.0062 | 0.0073 | 0.0084 | 0.0098 | 0.0114 | 0.0132 |
| 4 | 0.0046 | 0.0054 | 0.0063 | 0.0073 | 0.0085 | 0.0099 | 0.0115 | 0.0133 |
| 5 | 0.0047 | 0.0054 | 0.0063 | 0.0074 | 0.0086 | 0.0100 | 0.0116 | 0.0135 |
| 6 | 0.0040 | 0.0047 | 0.0054 | 0.0063 | 0.0073 | 0.0085 | 0.0098 | 0.0113 |
| 7 | 0.0035 | 0.0040 | 0.0046 | 0.0053 | 0.0061 | 0.0071 | 0.0081 | 0.0093 |
| 8 | 0.0040 | 0.0047 | 0.0054 | 0.0063 | 0.0073 | 0.0085 | 0.0098 | 0.0113 |
| 9 | 0.0047 | 0.0054 | 0.0063 | 0.0074 | 0.0086 | 0.0100 | 0.0116 | 0.0135 |
| 10 | 0.0058 | 0.0068 | 0.0080 | 0.0094 | 0.0110 | 0.0129 | 0.0151 | 0.0176 |
| 11 | 0.0070 | 0.0083 | 0.0098 | 0.0115 | 0.0136 | 0.0161 | 0.0189 | 0.0222 |
| 12 | 0.0084 | 0.0100 | 0.0119 | 0.0142 | 0.0168 | 0.0200 | 0.0236 | 0.0279 |
| 13 | 0.0099 | 0.0119 | 0.0142 | 0.0170 | 0.0203 | 0.0242 | 0.0288 | 0.0342 |
| 14 | 0.0121 | 0.0146 | 0.0176 | 0.0213 | 0.0256 | 0.0307 | 0.0367 | 0.0437 |
| 15 | 0.0145 | 0.0176 | 0.0214 | 0.0259 | 0.0314 | 0.0378 | 0.0454 | 0.0544 |
| 16 | 0.0175 | 0.0214 | 0.0262 | 0.0320 | 0.0389 | 0.0471 | 0.0569 | 0.0684 |
| 17 | 0.0207 | 0.0256 | 0.0315 | 0.0386 | 0.0472 | 0.0575 | 0.0696 | 0.0840 |

Table 23 – Risks for passenger ship at night in summer in District 2, by ship length and transit duration

| *Hours/Length* | *80* | *110* | *140* | *170* | *200* | *230* | *260* | *290* |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.0034 | 0.0040 | 0.0047 | 0.0055 | 0.0065 | 0.0076 | 0.0089 | 0.0104 |
| 2 | 0.0034 | 0.0040 | 0.0047 | 0.0056 | 0.0065 | 0.0077 | 0.0090 | 0.0105 |
| 3 | 0.0034 | 0.0041 | 0.0048 | 0.0056 | 0.0066 | 0.0077 | 0.0091 | 0.0106 |
| 4 | 0.0035 | 0.0041 | 0.0048 | 0.0057 | 0.0066 | 0.0078 | 0.0092 | 0.0107 |
| 5 | 0.0035 | 0.0041 | 0.0048 | 0.0057 | 0.0067 | 0.0079 | 0.0092 | 0.0108 |
| 6 | 0.0030 | 0.0035 | 0.0042 | 0.0049 | 0.0057 | 0.0066 | 0.0078 | 0.0090 |
| 7 | 0.0026 | 0.0030 | 0.0035 | 0.0041 | 0.0047 | 0.0055 | 0.0064 | 0.0074 |
| 8 | 0.0030 | 0.0035 | 0.0042 | 0.0049 | 0.0057 | 0.0066 | 0.0078 | 0.0090 |
| 9 | 0.0035 | 0.0041 | 0.0048 | 0.0057 | 0.0067 | 0.0079 | 0.0092 | 0.0108 |
| 10 | 0.0044 | 0.0052 | 0.0062 | 0.0073 | 0.0087 | 0.0102 | 0.0121 | 0.0143 |
| 11 | 0.0053 | 0.0064 | 0.0076 | 0.0091 | 0.0108 | 0.0129 | 0.0153 | 0.0181 |
| 12 | 0.0064 | 0.0077 | 0.0093 | 0.0112 | 0.0135 | 0.0161 | 0.0192 | 0.0229 |
| 13 | 0.0076 | 0.0092 | 0.0112 | 0.0136 | 0.0164 | 0.0197 | 0.0236 | 0.0282 |
| 14 | 0.0094 | 0.0115 | 0.0140 | 0.0171 | 0.0207 | 0.0251 | 0.0302 | 0.0363 |
| 15 | 0.0113 | 0.0139 | 0.0171 | 0.0209 | 0.0256 | 0.0311 | 0.0376 | 0.0453 |
| 16 | 0.0137 | 0.0170 | 0.0211 | 0.0260 | 0.0319 | 0.0389 | 0.0473 | 0.0572 |
| 17 | 0.0164 | 0.0205 | 0.0255 | 0.0315 | 0.0389 | 0.0477 | 0.0581 | 0.0705 |

## Table 24 – Risks for tanker at night in summer in District 1, by ship length and transit duration

| *Hours/Length* | *80* | *110* | *140* | *170* | *200* | *230* | *260* | *290* |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.0033 | 0.0037 | 0.0043 | 0.0049 | 0.0055 | 0.0063 | 0.0071 | 0.0081 |
| 2 | 0.0033 | 0.0038 | 0.0043 | 0.0049 | 0.0056 | 0.0063 | 0.0072 | 0.0082 |
| 3 | 0.0033 | 0.0038 | 0.0043 | 0.0049 | 0.0056 | 0.0064 | 0.0073 | 0.0082 |
| 4 | 0.0033 | 0.0038 | 0.0044 | 0.0050 | 0.0056 | 0.0064 | 0.0073 | 0.0083 |
| 5 | 0.0034 | 0.0038 | 0.0044 | 0.0050 | 0.0057 | 0.0065 | 0.0074 | 0.0084 |
| 6 | 0.0030 | 0.0034 | 0.0038 | 0.0043 | 0.0049 | 0.0056 | 0.0063 | 0.0072 |
| 7 | 0.0026 | 0.0029 | 0.0033 | 0.0037 | 0.0042 | 0.0047 | 0.0053 | 0.0060 |
| 8 | 0.0030 | 0.0034 | 0.0038 | 0.0043 | 0.0049 | 0.0056 | 0.0063 | 0.0072 |
| 9 | 0.0034 | 0.0038 | 0.0044 | 0.0050 | 0.0057 | 0.0065 | 0.0074 | 0.0084 |
| 10 | 0.0041 | 0.0047 | 0.0054 | 0.0062 | 0.0071 | 0.0082 | 0.0093 | 0.0107 |
| 11 | 0.0049 | 0.0057 | 0.0065 | 0.0075 | 0.0087 | 0.0100 | 0.0115 | 0.0132 |
| 12 | 0.0058 | 0.0068 | 0.0078 | 0.0091 | 0.0105 | 0.0122 | 0.0141 | 0.0163 |
| 13 | 0.0068 | 0.0079 | 0.0092 | 0.0108 | 0.0125 | 0.0146 | 0.0170 | 0.0197 |
| 14 | 0.0082 | 0.0096 | 0.0113 | 0.0133 | 0.0155 | 0.0182 | 0.0212 | 0.0247 |
| 15 | 0.0097 | 0.0115 | 0.0135 | 0.0160 | 0.0188 | 0.0221 | 0.0259 | 0.0303 |
| 16 | 0.0116 | 0.0138 | 0.0164 | 0.0194 | 0.0230 | 0.0272 | 0.0320 | 0.0376 |
| 17 | 0.0136 | 0.0163 | 0.0194 | 0.0232 | 0.0276 | 0.0327 | 0.0387 | 0.0457 |

Table 25 – Risks for tanker at night in summer in District 2, by ship length and transit duration

| *Hours/Length* | *80* | *110* | *140* | *170* | *200* | *230* | *260* | *290* |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.0032 | 0.0036 | 0.0042 | 0.0048 | 0.0054 | 0.0062 | 0.0071 | 0.0081 |
| 2 | 0.0032 | 0.0037 | 0.0042 | 0.0048 | 0.0055 | 0.0063 | 0.0071 | 0.0081 |
| 3 | 0.0032 | 0.0037 | 0.0042 | 0.0048 | 0.0055 | 0.0063 | 0.0072 | 0.0082 |
| 4 | 0.0032 | 0.0037 | 0.0043 | 0.0049 | 0.0056 | 0.0063 | 0.0072 | 0.0083 |
| 5 | 0.0033 | 0.0037 | 0.0043 | 0.0049 | 0.0056 | 0.0064 | 0.0073 | 0.0083 |
| 6 | 0.0029 | 0.0033 | 0.0037 | 0.0042 | 0.0048 | 0.0055 | 0.0063 | 0.0071 |
| 7 | 0.0025 | 0.0028 | 0.0032 | 0.0036 | 0.0041 | 0.0047 | 0.0053 | 0.0060 |
| 8 | 0.0029 | 0.0033 | 0.0037 | 0.0042 | 0.0048 | 0.0055 | 0.0063 | 0.0071 |
| 9 | 0.0033 | 0.0037 | 0.0043 | 0.0049 | 0.0056 | 0.0064 | 0.0073 | 0.0083 |
| 10 | 0.0040 | 0.0046 | 0.0053 | 0.0061 | 0.0070 | 0.0081 | 0.0093 | 0.0107 |
| 11 | 0.0048 | 0.0055 | 0.0064 | 0.0074 | 0.0086 | 0.0100 | 0.0115 | 0.0133 |
| 12 | 0.0057 | 0.0066 | 0.0077 | 0.0090 | 0.0105 | 0.0122 | 0.0141 | 0.0164 |
| 13 | 0.0066 | 0.0078 | 0.0091 | 0.0107 | 0.0125 | 0.0146 | 0.0170 | 0.0198 |
| 14 | 0.0080 | 0.0095 | 0.0112 | 0.0132 | 0.0155 | 0.0182 | 0.0214 | 0.0250 |
| 15 | 0.0095 | 0.0113 | 0.0134 | 0.0159 | 0.0188 | 0.0222 | 0.0262 | 0.0307 |
| 16 | 0.0114 | 0.0137 | 0.0163 | 0.0194 | 0.0231 | 0.0274 | 0.0324 | 0.0382 |
| 17 | 0.0134 | 0.0162 | 0.0194 | 0.0233 | 0.0278 | 0.0331 | 0.0393 | 0.0465 |

The shaded areas of Tables 20-25 mark those cases where the threshold of 0.0048 is exceeded or where a transit lasts more than 9 hours (in District 1) or more than 11 hours (in District 2). These cases would require a second pilot. As can be seen, a freighter (other than a tanker) transiting on a summer night between Quebec City and Trois-Rivières would have to take on a second pilot if its length is greater than 200 m; a freighter of 200 m or less would need a second pilot if the transit exceeds 9 hours. Between Les Escoumins and Quebec City, a freighter would not need to take on a second pilot unless the transit exceeds 11 hours (10 hours if the length is 290 m).

Passenger ships over 80 m would have to take on a second pilot between Quebec City and Trois-Rivières or between Trois-Rivières and Montreal. Ships of 80 m would need a second pilot only if the transit exceeds 9 hours. Between Les Escoumins and Quebec City, the second pilot would be needed in all cases with ships over 110 m. Ships between 80 and 110 m would need a second pilot if the transit exceeds 10 hours.

Between Quebec City and Montreal, tankers over 140 m would need a second pilot regardless of the transit duration. Smaller tankers would need a second pilot only if the transit exceeds 9 hours. Between Les Escoumins and Quebec City, tankers over 140 m would need a second pilot in all cases. Tankers of 80 m or less would need a second pilot if the transit exceeds 11 hours; those between 80 and 110 m would need a second pilot if the transit exceeds 10 hours; and those over 110 m but under 140 m would need a second pilot if the transit exceeds 9 hours.

To obtain a more comprehensive picture, we would obviously have to look at the situation during both summer and winter (when the lighted buoys have been taken out of the water and significant ice has built up) and during both night and day. Tables 26 and 27 show the results of such analyses for a 230 m freighter (other than a tanker). As can be seen, the risk for a 9-hour summer transit in the area between Quebec City and Trois-Rivières or between Trois-Rivières and Montreal falls from 0.0048 at night to 0.0036 during the day. On a winter day, it rises to 0.0051 if the lighted buoys have been removed and to 0.0067 if icing over has reached a stage that makes ship positioning difficult (the ice then conceals the spar buoys and distorts the radar image of the shoreline). On a winter night when the buoys have been removed and sufficient ice has formed, risk rises to 0.0095.

Table 26 – Risks for a 230 m freighter (other than tanker) in District 1, by season and transit duration

| *Hours* | *Day* | *Night* | *Buoys removed* | *Buoys removed + Ice* | *Buoys removed + Ice + Night* |
|---|---|---|---|---|---|
| 1 | 0.0035 | 0.0047 | 0.0050 | 0.0064 | 0.0091 |
| 2 | 0.0035 | 0.0047 | 0.0050 | 0.0065 | 0.0092 |
| 3 | 0.0036 | 0.0047 | 0.0050 | 0.0065 | 0.0093 |
| 4 | 0.0036 | 0.0048 | 0.0051 | 0.0066 | 0.0094 |
| 5 | 0.0036 | 0.0048 | 0.0051 | 0.0067 | 0.0095 |
| 6 | 0.0032 | 0.0041 | 0.0045 | 0.0056 | 0.0077 |
| 7 | 0.0029 | 0.0035 | 0.0038 | 0.0047 | 0.0061 |
| 8 | 0.0032 | 0.0041 | 0.0045 | 0.0056 | 0.0077 |
| 9 | 0.0036 | 0.0048 | 0.0051 | 0.0067 | 0.0095 |
| 10 | 0.0043 | 0.0060 | 0.0063 | 0.0086 | 0.0130 |
| 11 | 0.0050 | 0.0074 | 0.0077 | 0.0108 | 0.0170 |
| 12 | 0.0059 | 0.0090 | 0.0092 | 0.0134 | 0.0220 |
| 13 | 0.0067 | 0.0108 | 0.0109 | 0.0164 | 0.0276 |
| 14 | 0.0080 | 0.0134 | 0.0134 | 0.0208 | 0.0362 |
| 15 | 0.0094 | 0.0163 | 0.0162 | 0.0257 | 0.0460 |
| 16 | 0.0111 | 0.0200 | 0.0197 | 0.0321 | 0.0590 |
| 17 | 0.0130 | 0.0241 | 0.0236 | 0.0392 | 0.0736 |
| 18 | 0.0150 | 0.0285 | 0.0278 | 0.0470 | 0.0898 |

Table 27 – Risks for a 230 m freighter (other than tanker) in District 2, by season and transit duration

| *Hours* | *Day* | *Night* | *Buoys removed* | *Buoys removed + Ice* | *Buoys removed + Ice + Night* |
|---|---|---|---|---|---|
| 1 | 0.0019 | 0.0025 | 0.0027 | 0.0035 | 0.0050 |
| 2 | 0.0019 | 0.0025 | 0.0027 | 0.0035 | 0.0051 |
| 3 | 0.0019 | 0.0026 | 0.0027 | 0.0036 | 0.0051 |
| 4 | 0.0019 | 0.0026 | 0.0028 | 0.0036 | 0.0052 |
| 5 | 0.0019 | 0.0026 | 0.0028 | 0.0036 | 0.0052 |
| 6 | 0.0017 | 0.0022 | 0.0024 | 0.0031 | 0.0042 |
| 7 | 0.0015 | 0.0019 | 0.0021 | 0.0025 | 0.0034 |
| 8 | 0.0017 | 0.0022 | 0.0024 | 0.0031 | 0.0042 |
| 9 | 0.0019 | 0.0026 | 0.0028 | 0.0036 | 0.0052 |
| 10 | 0.0023 | 0.0033 | 0.0034 | 0.0047 | 0.0072 |
| 11 | 0.0027 | 0.0040 | 0.0042 | 0.0059 | 0.0094 |
| 12 | 0.0032 | 0.0049 | 0.0050 | 0.0074 | 0.0121 |
| 13 | 0.0036 | 0.0059 | 0.0060 | 0.0090 | 0.0153 |
| 14 | 0.0043 | 0.0073 | 0.0073 | 0.0114 | 0.0200 |
| 15 | 0.0051 | 0.0089 | 0.0089 | 0.0141 | 0.0255 |
| 16 | 0.0060 | 0.0110 | 0.0108 | 0.0177 | 0.0327 |
| 17 | 0.0071 | 0.0132 | 0.0129 | 0.0216 | 0.0407 |
| 18 | 0.0081 | 0.0157 | 0.0152 | 0.0259 | 0.0497 |

We may conclude that a ship of this size in District 1 would not have to take on a second pilot if the entire transit takes place during the daytime in the summer. However, in winter a second pilot would be needed in all cases once the lighted buoys had been removed.

Between Les Escoumins and Quebec City, the risk for an 11 hour summer transit drops from 0.0040 at night to 0.0036 during the daytime. On a winter day, a second pilot would be needed only for transits over 10 hours when ice has formed (removal of lighted buoys would not by itself dictate a second pilot). However, on a winter night a second pilot would be required in all cases once sufficient ice has formed.

Further analyses would be required to cover various ship sizes and types and to take docking into account. Docking, which generally occurs at the end of a transit, requires a high degree of concentration and attention on the part of the pilot. It cannot be done safely is the pilot is too tired. Applying the risk model shows that if docking is required, then the length of a transit without a second pilot must be reduced by 1-2 hours. Further study of a variety of situations would be required in order to be more precise. The results given in Tables 20-25 need to be supplemented to cover summer days as well as winter days and nights (with buoys removed and ice formation), and also to cover cases with and without docking in winter or in summer, during the day or at night. This would mean running 8,976 more cases through the model over and above the 816 cases that led to the results shown on the tables. It might also be of interest to look at ship length increments of less than 30 m. Thus if 10-m increments were used between 70 and 300 m, that would mean running an additional 10,608 cases through the model. All in all, the model would have to be run 29,376 times in order to cover all the situations needed to establish a new regulatory framework on the basis of the model parameters.

Also to be noted is that Tables 20-25 do not take into account any mitigation measures other than a second pilot, and they cover only the aggravating factors encountered during a normal trip, such as wind, currents and the width and sinuosity of the channel. Other mitigation measures available in the model but not used in the cases studied are bridge resource management, helmsman with local experience, and a good electronic navigation system that complies with standards and includes up-to-date electronic charts. Some of the aggravating factors included in the model are: ship in poor condition, inexperienced crew, poor-quality or defective navigating system. To take the various combinations of mitigating measures and aggravating factors into account would require tens of thousands of additional runs of the model over and above those already described. To accomplish this, processing and results analysis would need to be automated. Also, both the aggravating factors and the mitigation measures other than adding a second pilot would need to be fully validated.

The results presented in our tables confirm the value of a model, such as the one developed for this study, for estimating risk in relation to double pilotage. Even if the model cannot be run on a case-by-case basis each time a transit is made, we have shown that it can be used to review the regulatory framework by running a sufficiently large number of theoretical transits through it. Now the model needs to be fleshed out, in particular by validating the aggravating factors and the mitigation measures other than the use of a second pilot. In addition, processing and results analysis need to be optimized.

# 9. Recommendations

Based on the conclusions presented in section 8, six recommendations are proposed.

### Recommendation 1: Establish an acceptable risk level

The model developed for this project demonstrates the feasibility of quantifying the risk associated with ships transiting the St. Lawrence River. The model can also evaluate the contribution of a second pilot to reducing risk. The value of a second pilot depends on the degree of risk we are prepared to accept. In our model, risk is assigned a value between 0 and 30. Based on existing risk levels and conditions for double pilotage, we have identified 0.0048 as the maximum for navigating with a single pilot. Beyond that threshold, a second pilot should be assigned.

### Recommendation 2: Reduce transit duration for District 1

Our analysis shows that a transit of 11 hours in District 2 has a risk level comparable to a transit of 9 hours in District 1, for ships of the size that normally sail the St. Lawrence River. We recommend keeping the limit of 11 hours for District 2, but reducing the limit for District 1 to 9 hours.

### Recommendation 3: Use length between perpendiculars for ship size

Contrary to the current regulations, which use deadweight as an indicator of ship size, we believe it is preferable to use the length between perpendiculars, for all types of ship. This parameter has a greater impact on the ship's manoeuvrability and therefore on the risk associated with piloting in confined waters.

### Recommendation 4: Create double pilotage tables

The maximum risk of 0.0048 together with the maximum transit duration of 9 hours (District 1) or 11 hours (District 2) provide a foundation for rules determining whether a second pilot is required, depending on the size of the ship. We recommend creating double pilotage tables for each of the two districts based on:

1. Three ship types: freighter (other than tanker), tanker, passenger
2. Navigating season: summer or winter (after lighted buoys are removed and after a certain amount of ice has formed)

3. Time of trip: day or night
4. Special condition: with or without docking

Figures 4 to 9 exemplify such tables for each of the three types of ship sailing at night in summer. The model could be used to create similar tables to cover all the conditions set out above. A total of 72 tables would be needed (3 ship types x 3 seasons x 2 times of day x 2 special conditions x 2 districts).

Recommendation 5: Add other mitigation measures and aggravating factors

Measures other than a second pilot could be considered in order to reduce risk. In this study, we have looked at three:

- bridge resource management;
- crew that has experience navigating the St. Lawrence;
- a good electronic navigating system that complies with standards and includes up-to-date S-57 electronic charts.

Use of one or another of these measures could make it possible to avoid having a second pilot. However, our model would need to be validated before we could recommend changing the regulations in that regard. Also, mechanisms would need to be in place to determine whether such other mitigation measures are in fact present on a ship, and whether they meet whatever requirements may be defined.

Figure 4 – Double pilotage table for freighter (other than tanker) at night in summer in District 1, by ship length and transit duration

<table>
<tr><th>Hours/Length</th><th>80</th><th>110</th><th>140</th><th>170</th><th>200</th><th>230</th><th>260</th><th>290</th></tr>
<tr><td>1</td><td colspan="6" rowspan="9">One pilot</td><td colspan="2" rowspan="9"></td></tr>
<tr><td>2</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td></tr>
<tr><td>5</td></tr>
<tr><td>6</td></tr>
<tr><td>7</td></tr>
<tr><td>8</td></tr>
<tr><td>9</td></tr>
<tr><td>10</td><td colspan="8" rowspan="8">Two pilots</td></tr>
<tr><td>11</td></tr>
<tr><td>12</td></tr>
<tr><td>13</td></tr>
<tr><td>14</td></tr>
<tr><td>15</td></tr>
<tr><td>16</td></tr>
<tr><td>17</td></tr>
</table>

Figure 5 – Double pilotage table for freighter (other than tanker) at night in summer in District 2, by ship length and transit duration

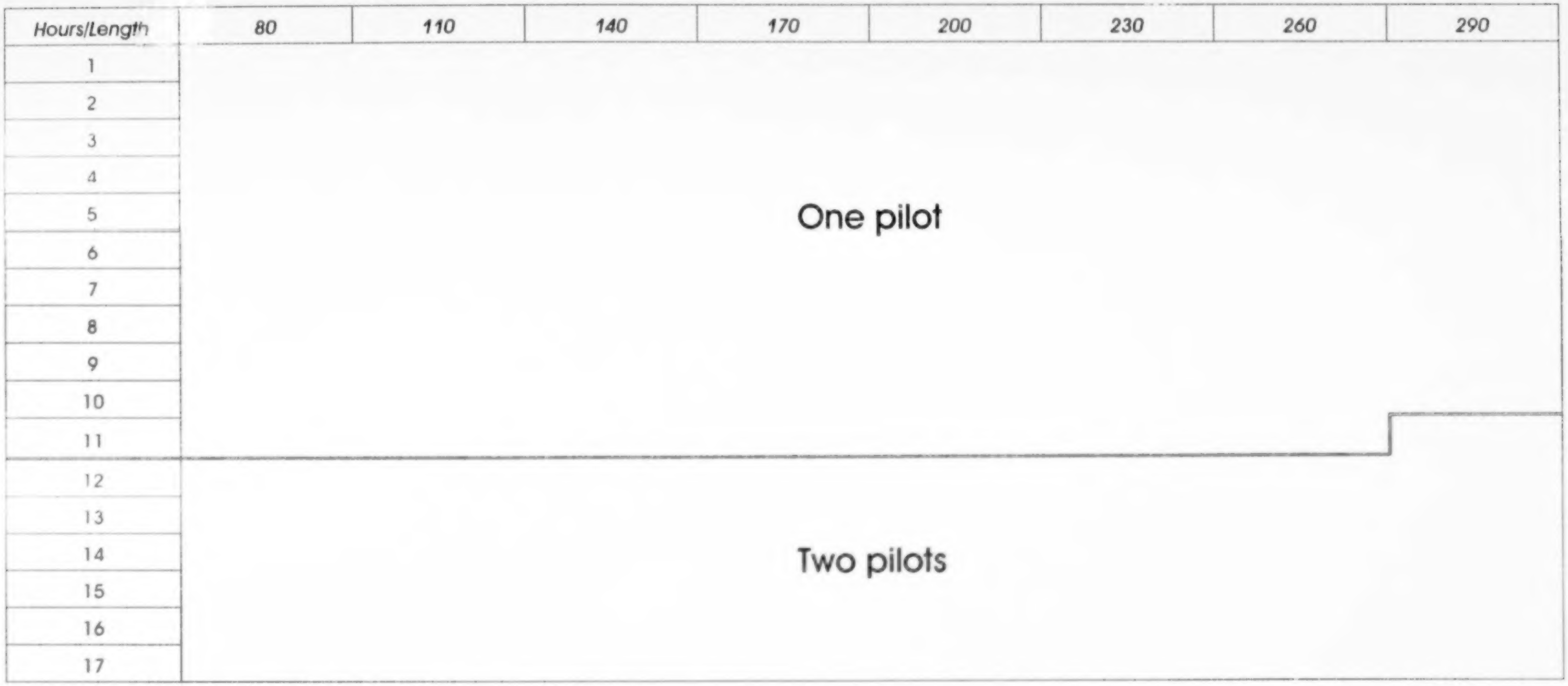


Figure 6 – Double pilotage table for passenger ship at night in summer in District 1, by ship length and transit duration

| *Hours/Length* | *80* | *110* | *140* | *170* | *200* | *230* | *260* | *290* |
|---|---|---|---|---|---|---|---|---|
| 1 | One pilot | Two pilots |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |  |  |
| 4 |  |  |  |  |  |  |  |  |
| 5 |  |  |  |  |  |  |  |  |
| 6 |  |  |  |  |  |  |  |  |
| 7 |  |  |  |  |  |  |  |  |
| 8 |  |  |  |  |  |  |  |  |
| 9 |  |  |  |  |  |  |  |  |
| 10 |  |  |  |  |  |  |  |  |
| 11 |  |  |  |  |  |  |  |  |
| 12 |  |  |  |  |  |  |  |  |
| 13 |  |  |  |  |  |  |  |  |
| 14 |  |  |  |  |  |  |  |  |
| 15 |  |  |  |  |  |  |  |  |
| 16 |  |  |  |  |  |  |  |  |
| 17 |  |  |  |  |  |  |  |  |

Figure 7 – Double pilotage table for passenger ship at night in summer in District 2, by ship length and transit duration

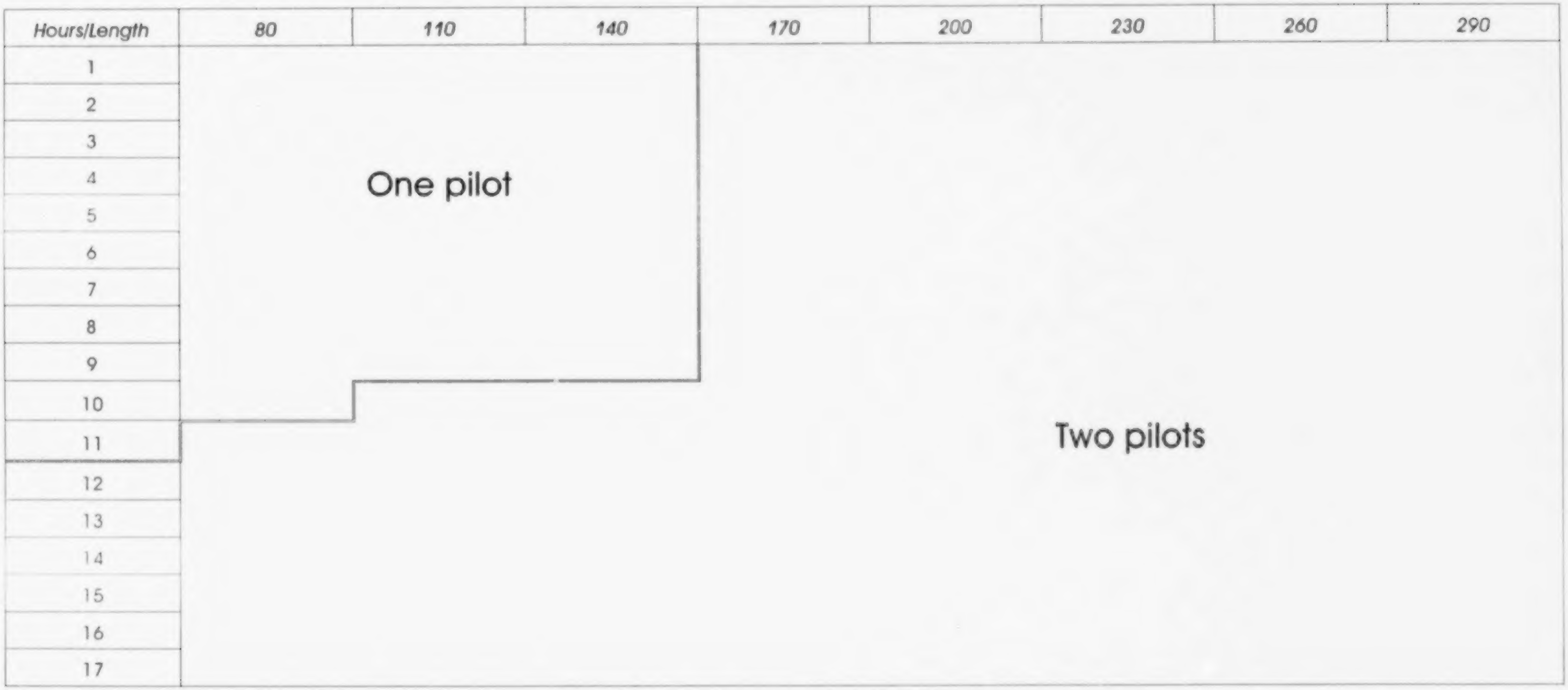
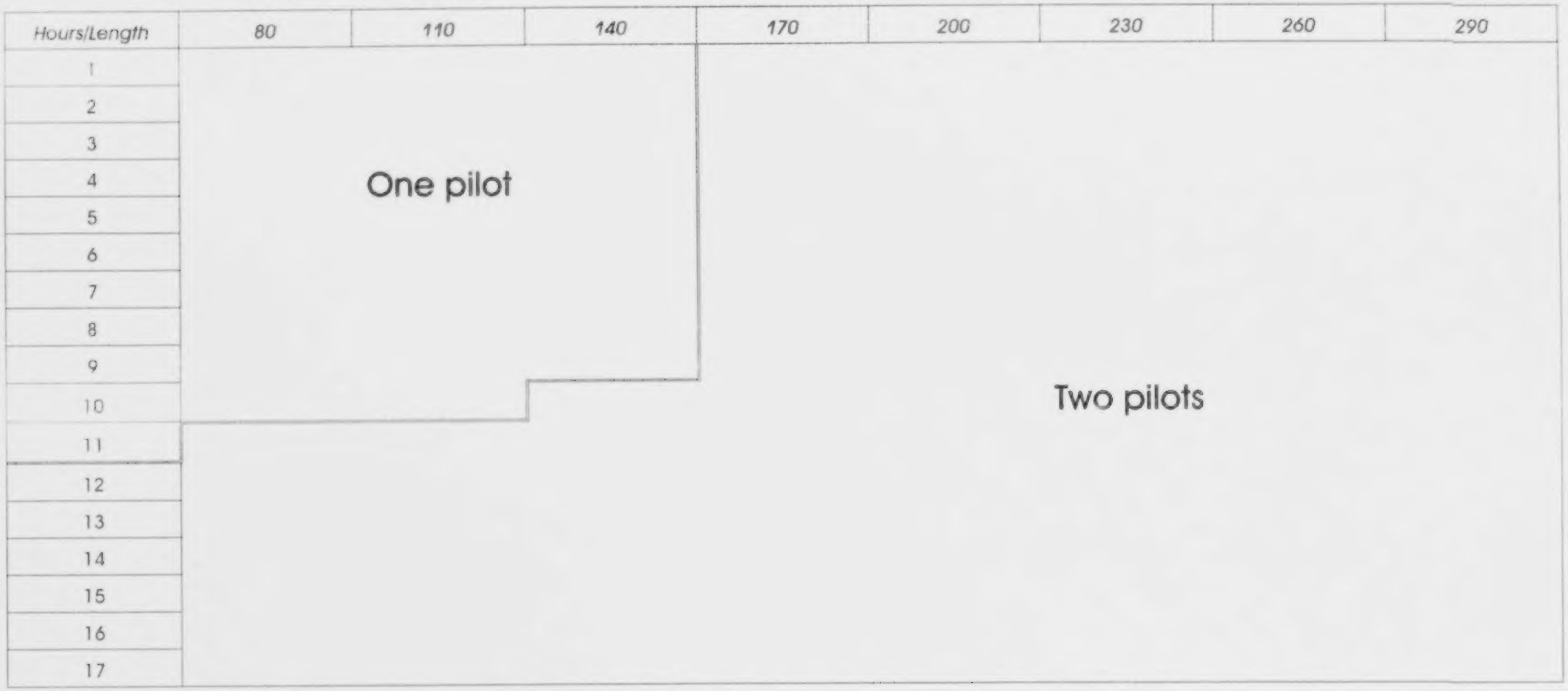


Figure 8 – Double pilotage table for tanker at night in summer in District 1, by ship length and transit duration

<table>
<tr><th>Hours/Length</th><th>80</th><th>110</th><th>140</th><th>170</th><th>200</th><th>230</th><th>260</th><th>290</th></tr>
<tr><td>1</td><td colspan="3" rowspan="9">One pilot</td><td colspan="5" rowspan="9">Two pilots</td></tr>
<tr><td>2</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td></tr>
<tr><td>5</td></tr>
<tr><td>6</td></tr>
<tr><td>7</td></tr>
<tr><td>8</td></tr>
<tr><td>9</td></tr>
<tr><td>10</td><td colspan="8" rowspan="8">Two pilots</td></tr>
<tr><td>11</td></tr>
<tr><td>12</td></tr>
<tr><td>13</td></tr>
<tr><td>14</td></tr>
<tr><td>15</td></tr>
<tr><td>16</td></tr>
<tr><td>17</td></tr>
</table>

Figure 9 – Double pilotage table for tanker at night in summer in District 2, by ship length and transit duration



Regarding the aggravating factors that may increase risk, Figures 4 to 9 assume normal navigating conditions, a ship of average manoeuvrability and in good condition, and a typical crew. If these assumptions are not satisfied, the risk level could increase enough to exceed our threshold value. A ship that would normally be exempted by Figures 4 to 9 would then be required to have a second pilot.

Incorporating other mitigation measures and aggravating factors would make the use of the tables considerably more cumbersome. It would probably not be worthwhile unless the model is being used on a case-by-case basis. Still, other methods of reducing risk cannot simply be ignored, nor can factors that may increase risk. It must also be borne in mind that while pilotage conditions are always changing, the amendment process for regulations is very slow (the most recent amendments were made a decade ago).

Recommendation 6: Continue to develop the model

It has been shown that our model can objectively establish the level of risk associated with ships navigating the St. Lawrence River. However, if we wish to create tables for all conditions, as discussed in Recommendation 4, then the model will need to be further developed. The process of running thousands of theoretical transits needs to be speeded up, and the analysis of results needs to be optimized. It would also be desirable to develop an interface that facilitates use of the model by users who are not familiar with it.

We have also seen that the model can evaluate the impact of other mitigation measures and of aggravating factors. However, validation work remains to be done if this aspect of the model is to meet needs. Once that work is done, the double pilotage tables would be changed accordingly. This work would also make it possible to explore in greater depth how the model could be used as a tool to determine double pilotage without the need to consult tables.

We therefore recommend that work on developing the model continue.

## Bibliography

Arnedt, J., Wilde, G., Munt, P., and MacLean, A. (2000) Simulated driving performance following prolonged wakefulness and alcohol consumption: separate and combined contributions to impairment. *Journal of Sleep Research*, 9:233-241.

Arnedt, J., Wilde, G., Munt, P., and MacLean, A. (2001) How do prolonged wakefulness and alcohol compare in the decrements they produce on a simulated driving task? *Accident Analysis and Prevention*, 33 (3): 47-54.

Audet, J., and Victor, A. (1999) *Pilotage Certificate Training for Laurentian Region (District 2 Quebec City to Les Escoumins) Volume 1: Development of Program*. TP 13458E. Transportation Development Centre, Transport Canada.

Audet, J., and Victor, A. (1999) *Pilotage Certificate Training for Laurentian Region (District 2 Quebec City to Les Escoumins) Volume 2: Training guide and Evaluation guide – General information.* TP 13458E. Transportation Development Centre, Transport Canada.

Audet, J., and Victor, A. (1999) *Pilotage Certificate Training for Laurentian Region (District 2 Quebec City to Les Escoumins) Volume 3: Evaluation guide (protected).* TP 13458E. Transportation Development Centre, Transport Canada.

Australian Transport Safety Bureau (2002) Investigation into the contact by the Russian flag container ship *Maksim Mikhaylov*. ATSB report 168.

Australian Transport Safety Bureau (2002) Investigation into the grounding of the Greek registered ship *Doric Chariot*. ATSB report 182.

Australian Transport Safety Bureau (2003) Investigation into the grounding of the Liberian registered container ship *ANL Excellence*. ATSB report 181.

Axys Environmental Consulting, et al. (2000) *Cumulative Effects Assessment – Training Workshop*. Canadian Environmental Assessment Agency.

Batchelor Marine Consulting Services Inc. (2002) *Review of the 105 mile rule*.

Berger, Y. (1984) *Port Phillip Sea Pilots: An Occupation at Risk.* PhD Thesis. Latrobe University, Australia.

Bernier (1970) *Study of Canadian Pilotage.* Report of the Royal Commission on Pilotage.

Bourgeois, L.P., Cimon, P., and Larouche, L. (1998) *Rapport final du comité d'étude sur le fardeau occupationnel des pilotes du Bas-Saint-Laurent.*

Brander-Smith, D., Therrien, D., and Tobin, S. (1990) *Public Review Panel on Tanker Safety.*

Canadian Coast Guard (1999) *Canadian Waterways National Manoeuvring Guidelines: Channel Design Parameters.* Waterways Development Division, Aids to Navigation, Fisheries and Oceans Canada.

Canadian Coast Guard (2001) *Rapport sur les essais de systèmes portatifs DGPS sur le Saint-Laurent.* Aids to Navigation Division, Marine Programs, Fisheries and Oceans Canada.

Corporation of Lower St. Lawrence Pilots (2003) *Étude de risque nécessitant le double pilotage dans la circonscription n° 2 de la région de l'Administration de pilotage des Laurentides.*

Corporation of Mid St. Lawrence Pilots (2001) *Rapport d'évaluation du navire porte-conteneurs* Cast Progress.

Corporation of Mid St. Lawrence Pilots (2002) *Analyse des risques en matière de pilotage pour la circonscription n° 1 de la région de l'Administration de pilotage des Laurentides.*

Corporation of Mid St. Lawrence Pilots (2003) *Application de la MGRP à la pratique du double pilotage dans la circonscription n° 1 de la région de l'Administration de pilotage des Laurentides.*

Dancosse, G. (1993) *Examination of Compulsory Double Pilotage in the Laurentian Pilotage Authority Area.*

Dawson, D., and Reid, K. (1997) Fatigue, alcohol and performance impairment. *Nature*, 388: 235.

Dawson, D., Roach, G., Reid, K., and Baker, A. (1997) *Australian railways: shiftwork and workload analysis – final report.* University of South Australia, Centre for Sleep Research.

Dawson, D., Fletcher, A., and Hussey, F. (1999) *Fatigue and transport: Report to the Neville Committee*. University of South Australia, Centre for Sleep Research.

DDH Environnement Ltée (2002) *Évaluation des risques en relation avec la taille, la jauge et le type de navires canadiens assujettis au pilotage obligatoire sur le fleuve Saint-Laurent – Module 1*.

DDH Environnement Ltée (2003) *Analyse statistique des accidents et des incidents impliquant des navires commerciaux canadiens et étrangers survenus sur le fleuve Saint-Laurent et la rivière Saguenay*.

Duran, Jean-Yves (2000) *Arbitrage sur le double pilotage concernant les navires* Canmar Pride, Canmar Honour *et* OOCL Belgium.

Falleti, M., Maruff, P., Collie, A., Darby, D., and McStephen, M. (2003) Qualitative similarities in cognitive impairment associated with 24 h of sustained wakefulness and a blood alcohol concentration of 0.05%. *Journal of Sleep Research*, 12 (4): 265-274.

Gauthier, J. (1996) *Rapport d'examen concernant les exemptions de pilotage et la certification dans la région de l'Administration de pilotage des Laurentides*.

Grier, R., Warm, J., Dember, W., Matthews, G., and Galinsky, T. (2003) The vigilance decrement reflects limitations in effortful attention, not mindlessness. *Human Factors* 45 (3): 349-359.

Harrison, Y., and Horne, J. (2000) The impact of sleep deprivation on decision making: a review. *Journal of Experimental Psychology – Applied*, 6 (3): 236-249.

Hensen, H. (1999) *Ship bridge simulators a project handbook*, Nautical Institute.

Hockey, G., Healey, A., Crawshaw, M., Wastell, D., and Sauer, J. (2003) Cognitive demands of collision avoidance in simulated ship control. *Human Factors* 45 (2): 252-265.

Innovation maritime (2002) *Étude sur les limites de l'utilisation des cartes électroniques pour le pilotage en eaux restreintes*.

Jacques, Y., Pelletier, S., and Ringuette, G. (2001) *Rapport sur les essais de systèmes portatifs DGPS sur le Saint-Laurent.*

Judson, B., Shortreed, J., and Reid, J.D. (1999). *Risk-based design method for aids to navigation in the St. Lawrence River*, TP 13468E. Transportation Development Centre of Transport Canada, and Canadian Coast Guard.

Kriebel, D.L., Mayer, R.H., and Water, J.K. (1999) *Impacts of navigation trends on channel usage and design.*

LaHaye, G. (1992) *Étude sur les facteurs et situations de risques en matière de pilotage – Zones de pilotage obligatoires.*

Lamond, N., and Dawson, D. (1999) Quantifying the performance impairment associated with fatigue. *Journal of Sleep Research*, 8: pp. 255-262.

Larouche, L. (1998) *Rapport final du Comité d'étude sur le fardeau occupationnel des pilotes du Bas Saint-Laurent.*

Luna, T.D., French, J., and Mitcha, J.L. (1997). A study of USAF air traffic controller shiftwork: Sleep, fatigue, activity, and mood analyses. *Aviation, Space, and Environmental Medicine, 68(1)*, 18-23.

Marine Safety Commitee, International Maritime Organisation (2001) *Guidance on fatigue mitigation and management.*

Moray, N. (1986) Monitoring behaviour and supervisory control. In Boff, K., Kaufman, L., Thomas, J. (eds.) *Human Perception and Human Performance: Volume II*. New York: Wiley.

Parasuraman, R. (1986) Vigilance, monitoring, and search. In Boff, K., Kaufman, L., Thomas, J. (eds.) *Human Perception and Human Performance: Volume II*. New York: Wiley.

Parker, A., Briggs, L., Hubinger, L., Folkard, S., and Green, L. (1998) *A Survey of the Work and Sleep Patterns of Great Barrier Reef Pilots*. Canberra: Australian Maritime Safety Authority.

Paul, M., and Guerrier, P. (2000) *PEPEC: A Response Guide Dealing with Protecting Public Health in Case of Drinking Water Contamination by an Oil or Chemical Spill on the St. Lawrence River*. 23rd Arctic and Marine Oilspill (AMOP) Technical Seminar, Vancouver (BC). Environment Canada, pp. 987-990.

PIANC-AIPCN (International Navigation Association) (1997) *Approach channels, a guide for design*.

Rhodes & Associates (2003) *Fatigue Management Training for Canadian Marine Pilots*. TP 14127E. Transportation Development Centre, Transport Canada.

Rhodes, W., and Gil, V. (2002) *Development of a Fatigue Management Program for Canadian Marine Pilots*. TP 13958E. Transportation Development Centre, Transport Canada.

Rhodes, W., Heslegrave, R., Ujimoto, K.V., Hahn, K., Zanon, S., Marino, A., Côté, Szlapetis, I., and Pearl, S. (1996) *Impact of Shiftwork on Air Traffic Controllers, Phase II: Analysis of Shift Schedule Effects on Sleep, Performance, Physiology and Social Activities*. TP 12816E. Transportation Development Centre, Transport Canada.

Ricard, M., and Thériault, F. (2002) *Évaluation des risques en relation avec la taille, la jauge et le type de navires canadiens assujettis au pilotage obligatoire sur le fleuve Saint-Laurent – Module 2*.

Rosekind, M.R., et al. (1994) Fatigue in operational settings: Examples from the aviation environment. *Human Factors* 36: 327-338.

Saint-Laurent Vision 2000 and Institut national de santé publique du Québec (2000). *Guide d'intervention en cas de déversement en milieu fluvial pour les directions régionales de santé publique du Québec*. Programme Saint-Laurent Vision 2000, domaine d'intervention Santé humaine.

Shipley, P. (1978) *A Human Factors Study of Marine Pilotage*. Department of Industry, UK.

Société linnéenne du Québec and Les Amis de la vallée du Saint-Laurent (2003) *Le pilotage maritime sur le Saint-Laurent et l'analyse des risques : synthèse sommaire des informations et des analyses*. Stratégie Saint-Laurent — Commission environnementale.

Temple, J., Warm, J., Dember, W., Jones, K., Le Grange, C., and Matthews, G. (2000) The effects of signal salience and caffeine on performance, workload, and stress in an abbreviated vigilance task. *Human Factors* 42 (2): 183-194.

Transport Canada (1995) *Working paper on marine pilotage in Canada.*

Transport Canada (1995) *National Marine Policy.*

Transport Canada (1996) *Canada Marine Act.*

Transport Canada (1999) *Ministerial Review of Outstanding Pilotage Issues – Report to Parliament.*

Transport Canada (2001) *Pilotage Risk Management Methodology.* TP 13741E. Ottawa: Personnel Standards and Pilotage Branch of Marine Safety Directorate.

Transport Canada (2002) *Port State Control.* TP 13595E.

Transport Canada (2003) *Evaluation of the Potential Impact of the New 294-M Container Ships on Navigational Safety and Environmental Protection, Progress Report.*

Transportation Safety Board of Canada (1990) *Grounding of the ENERCHEM FUSION.* Safety report number M90L3011.

Transportation Safety Board of Canada (1991a) *Collision between the CANADIAN EXPLORER and the LAFRENAIS.* Safety report number M91L3031.

Transportation Safety Board of Canada (1991b) *Bottom contact of the IRVING NORDIC.* Safety report number M91L3012.

Transportation Safety Board of Canada (1991c) *Grounding of the HALIFAX.* Safety report number M91L3015.

Transportation Safety Board of Canada (1992) *Passage rapproché entre le IRVING CANADA et le TERRA NOVA.* Safety report number M92L3028.

Transportation Safety Board of Canada (1993a) *Striking by the bulk carrier NIRJA of the tanker HAMILTON ENERGY*. Safety report number M93C003.

Transportation Safety Board of Canada (1993b) *Bottom contact of the bulk carrier CANADIAN EXPLORER*. Safety report number M93L0001.

Transportation Safety Board of Canada (1993c) *Grounding of the TRANSASPIRATION*. Safety report number M93W0011.

Transportation Safety Board of Canada (1995a) *Grounding of the OLYMPIC MENTOR*. Safety report number M95C0120.

Transportation Safety Board of Canada (1995b) *Collision between the CICERO and the ZIEMIA ZAMOJSKA*. Safety report number M95L000.

Transportation Safety Board of Canada (1995c) *A safety study of the operational relationship between ship masters/watchkeeping officers and marine pilots.* Safety report number SM9501.

Transportation Safety Board of Canada (1996) *Near-collision between the cruise ship STATENDAM and the tug-barge unit BELLEISE SOUND/RADIUM 622, Discovery Passage, British Columbia.* Safety report number M96W0187.

Transportation Safety Board of Canada (1997c) *Grounding of the bulk carrier RAVEN ARROW*. Safety report number M97W0197.

Transportation Safety Board of Canada (1997b) *Grounding of the bulk carrier VENUS Bécancour Harbour, St. Lawrence River, Québec.* Safety report number M97L0030.

Transportation Safety Board of Canada (1997a) *Striking – oil tanker IRVING ARCTIC Traverse Cap-Santé, St. Lawrence River, Québec.* Safety report number M97L0019.

Transportation Safety Board of Canada (1998a) *Grounding of the ALGOLAKE*. Safety report number M98C0066.

Transportation Safety Board of Canada (1998b) *Contact with bottom by bulk carrier PACIFIC DOLPHIN and tug SEASPAN FALCON, Port Moody, British Columbia.* Safety report number M98W0019.

Transportation Safety Board of Canada (1999a) *Grounding of the PATERSON.* Safety report number M99C0003.

Transportation Safety Board of Canada (1999b) *Grounding of the SUNNY BLOSSOM.* Safety report number M99C0027.

Transportation Safety Board of Canada (1999c) *Grounding of the NORWEGIAN SKY.* Safety report number M99L0098.

Transportation Safety Board of Canada (1999d) *Grounding and Constructive Total Loss of the Bulk Carrier ALCOR.* Safety report number M99L0126.

U.S. Coast Guard (1990) *The effect of ship inherent controllability on pilot performance: the simulator experiment CG-D-10-90.*

U.S. Coast Guard (1991) *The effect of ship inherent controllability on pilot performance: evaluation and prediction CG-D-10-93.*

U.S. Department of Naval Architecture (1999) *Analysis of US Coast Guard accident data; Impacts of navigation trends on channel usage and design.*

Westheimer, G. (1986) The eye as an optical instrument. In Boff, K., Kaufman, L., Thomas, J. (eds.) *Human Perception and Human Performance: Volume II.* New York: Wiley.

Wickens, C. (1999) *Engineering Psychology.* Englewood Cliffs: Prentice Hall.

Williams, J.C. (1988) *A data-based method for assessing and reducing human error to improve operational performance.* 4th IEEE Conference on Human Factors in Nuclear Power Plants. New York: Institute for Electrical and Electronic Engineers, pp. 436-450.

Williamson, A., Feyer, A., Mattick, R., Friswell, R., and Finlay, S. (2001) *Developing measures of fatigue using an alcohol comparison to validate the effects of fatigue on performance*. ATSB Report 189. Canberra: Australian Transport Safety Bureau.

# APPENDIX 1

# Human Factors Literature Review

# Human Factors Literature Review

## Two-Pilot Risk Assessment Project

## 1. Human Factors Issues

Human factors concerns were examined in the marine incident investigation reports and other related documentation. Details are discussed in the following sections. A number of general human factors issues were identified during the review. These included:

- The impact of fatigue on performance
- Nature and level of mental workload and its relationship to performance
- Piloting requirements for sustained vigilance and response time
- Limitations of human perception
- Cognitive aspects of Bridge Resource Management (BRM)

## 2. Human Factors Issues Affecting Single and Two-Pilot Operations

This section addresses the human factors issues that are likely to have the greatest effect on single and two-pilot operations. The discussions are supported by the relevant research and information provided by experts in human factors. Specific incidents as described by TSBC safety reports that may apply are also indicated.

### 2.1 Impact of Fatigue on Pilot Performance

Fatigue is a known factor for marine pilot operations where irregular working hours can lead to sleep debts and building fatigue levels (Berger, 1984; Parker et al., 1999; Rhodes and Gil, 2002; and Shipley, 1978). The TSBC has identified severe fatigue as a contributing factor to several incidents:

- Grounding of the Raven Arrow (TSBC, 1997a)
- Hamilton Energy striking by the Nirja (TSBC, 1993a)
- Bottom contact by the Canadian Explorer (TSBC, 1993b)
- Grounding of the Venus (TSBC, 1997b)

The Australian Transportation Safety Bureau (ATSB) has also identified a number of incidents where fatigue was a major contributing factor.

- ATSB report number 181 – Grounding of the ANL Excellence – Pilot missed visual cues and ordered incorrect course alteration, as well as not following his usual procedure for that section of pilotage. (ATSB, 2003)
- ATSB report number 168 – contact by the Russian flag container ship Maksim Mikhaylov – The pilot showed signs of fatigue and an analysis of his sleep indicated that

during the passage his levels of fatigue were over the accepted threshold according to a fatigue risk-based assessment.

- ATSB report 182 - grounding of the Greek registered ship Doric Chariot – rather than just resting, the pilot fell asleep at a point in the passage when he needed to monitor the ships location and prepare for an alteration.

### 2.1.1 Fatigue Effects on Reaction Time and Vigilance Performance

Several research teams (Arnedt et al., 2000 and 2001; Dawson and Reid, 1997; Lemond and Dawson, 1999; and Williamson et al., 2000) have measured the impact of fatigue on vigilance and reaction time, comparing these results directly to the results of the same measurements while the subjects were performing the same tasks while having 0.05 and 0.10 percent blood alcohol concentration (BAC). Falleti et al. (2003) examined qualitative effects of alcohol or fatigue on attention, memory, learning, and decision-making, finding similar or greater negative effects of fatigue compared with the effects of 0.05 percent BAC.

Figures 1-1 and 1-2 have been taken from research carried out by scientists (Dawson and Reid, 1997; Lemond and Dawson, 1999; Williamson et al., 2000) investigating the comparative performance changes that occur when affected by specific levels of blood alcohol or hours of wakefulness. The research mentioned here has been replicated and verified elsewhere (Arnedt et al., 2000 and 2001; Falleti et al., 2003). Pilot performance is includes several cognitive activities including decision making, attention, communications, reaction time and vigilance. Two performance factors of utmost importance for marine pilots are reaction time and vigilance. Any decrement in reaction time and vigilance can be critical to effective pilotage.

Figure 1-1 (adapted from Williamson et al., 2000) shows the potential performance of pilots after being awake for 4 hours and carrying a 4-hour sleep debt. The graph's data is taken directly from Williamson et al. (2000) and overlaid with the hours for the passage and the estimated sleep debt (accumulated hours of lost sleep due to the irregular work hours) and time awake prior to the passage (i.e. waiting for the ship). The lost hours of sleep estimate is based on the fact that Canadian marine pilots, on average, only get about 4.5 to 5 hours of sleep during the day when working through the night (Rhodes and Gil, 2002). Given that a majority of transits are at night, particularly during the winter where almost all are through the night in the lower St. Lawrence, the pilots usually have a few night passages in a row before having a few days of night-time sleep to recover. Note that in Figure 1-1, the pilot is likely to be performing below acceptable levels after being awake for 11 hours.

Even without a sleep debt (Figure 1-2) the pilot will begin to experience poorer reaction time performance halfway through an 11-hour passage. In fact, just after 7 hours of passage the pilot can expect to be performing below acceptable levels (similar to having a 0.10 % blood alcohol concentration or BAC). It is highly likely that this situation will worsen as the pilot remains awake for longer periods of time. Note in Figure 1-2 that after 7 hours of passage, reaction time is suboptimal. This would be an ideal time for the pilot to be relieved.

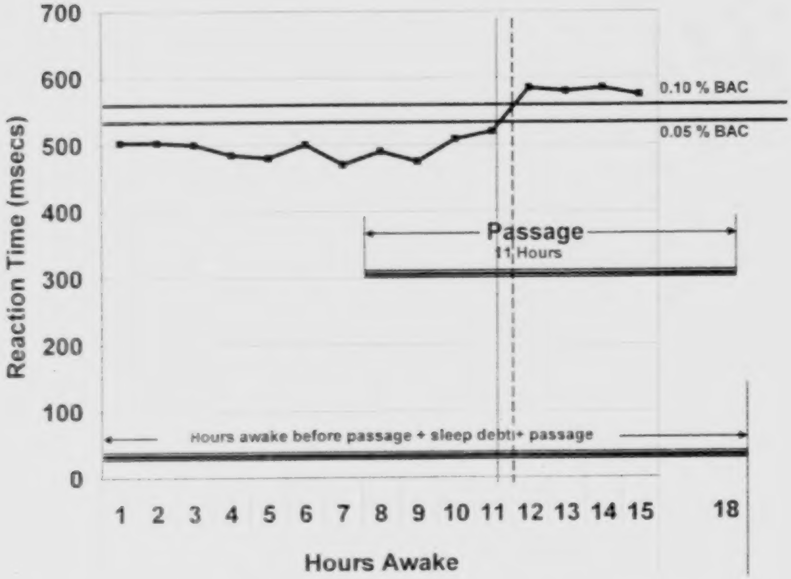


Figure 1-1 Reaction Time (Adapted from Dawson and Reid, 2001)

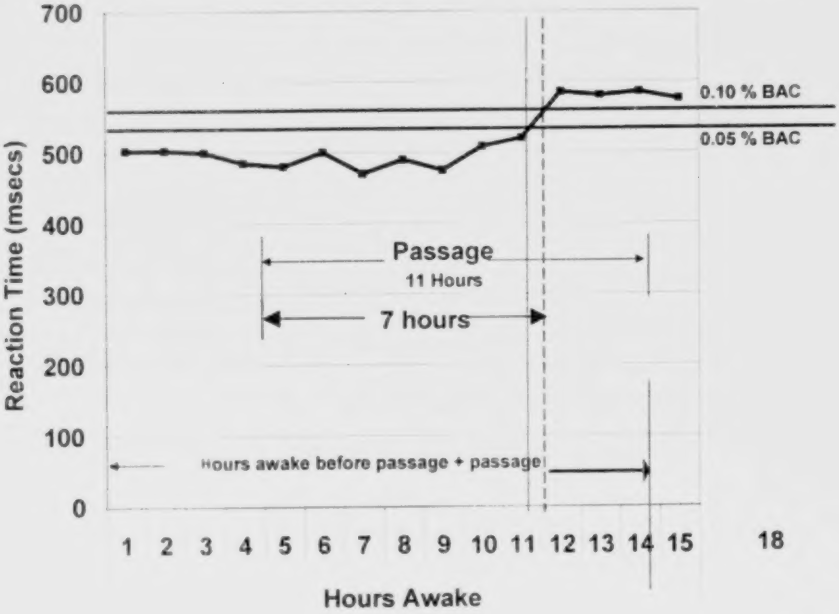


Figure 1-2 Reaction Time Performance without Prior Sleep Debt (Adapted from Dawson and Reid, 2001)

Figure 1-3 shows the expected vigilance performance after being awake for several hours and suffering a sleep debt of only 4 hours. At the end of an eleven-hour passage the pilot will be functioning well below acceptable levels. Note that at this point he/she would be performing at a level that is similar to that found if he/she had had a few drinks. This comparison is suggested because we all can identify with the change in our abilities after we ingest certain levels of alcohol. It is important to understand that fatigue has a similar effect and that if we do not get relief soon when in such a state, we can become increasingly less able to perform our duties effectively. if this pilot was then to dock the vessel at a port at the end of the passage, that individual will be operating at a suboptimal level of visual and reaction time performance.

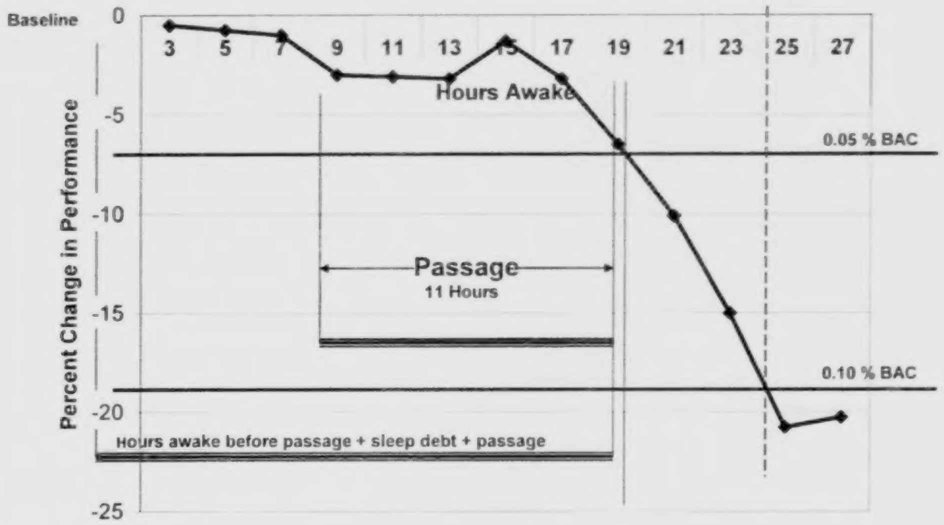


**Figure 1-3 Vigilance Performance (Adapted from Dawson and Reid, 2001)**

Working through the night also requires that the pilot work at a time when the body would rather be sleeping. This results in an additional reduction in performance caused by the increase in sleepiness that occurs between 02:00 and 06:00. When this further decrease in performance is added to that caused by the fatigue due to long hours awake, the pilot will find that he/she must work harder to maintain an acceptable level of performance.

The longer the pilot remains awake, the greater the impact on performance. After 11 hours of wakefulness, working between 02:00 and 06:00 results in suboptimal reaction time performance. Periods of wakefulness greater than 17 hours will result in suboptimal vigilance performance when working through the 02:00 to 06:00 time period. In fact similar levels of performance can be expected when working less lours than that above if the pilot is already sleep deprived. As mentioned above, this is probable given the pilot's irregular work hours and high likelihood of daytime sleep rather than sleeping during the night (Rhodes and Gil, 2002).

Since pilots work irregular shifts and scheduling pilotage is highly unpredictable, the pilotage, pilots and shipping companies must understand fatigue and mange fatigue risk as well as practicable. Rules for the assignment of pilots to ships should take fatigue risk and the duration of passages into account. Some pilotage corporations in Australia are already applying fatigue risk rules in the assignment of pilots (described in ATSB incident report 181 – ATSB, 2003).

## 2.2 Mental Workload

### 2.2.1 Nature of Mental Workload

Mental workload is the measure of the amount of mental resources being used at any given time. The resources are limited and their use depends on individual differences and interactions. For example, cognitive tasks involve the use of memory, information processing (including decision making), and perception. These are the resources available to humans working doing cognitive activities. The limits of each of these resources vary for each person, and the choice of how they are used is variable. Consequently, several strategies exist that can be used to manage these resources while problem solving and responding to changing information. Some will rely on memory more, while others will reduce the number or priority of the tasks they must handle. Some will rely on their ability to process data quickly, moving on to each of the next tasks in rapid succession. The point where the limits of mental workload is exceeded can be described as that point where the human operator can no longer effectively apply the strategies, and performance begins to degrade unacceptably. People can recognize this and report when this happens. Furthermore, their physiology can also indicate when such a state occurs. Heart rate will increase and brainwave activity will show tell-tale spikes in the waveforms.

The implication that arises from the nature of mental workload is that the working environment must be such that the limits of this use of mental resources, i.e. mental workload, is not reached, particularly during the performance of critical tasks. However, the lack of activity and stimulus will also evoke similar physiological responses when people are under stimulated and then must respond to a critical situation. They will feel overwhelmed and find it difficult to "get-up-to-speed". In fact, if this situation continues the same subjective feelings and physiological responses seen when mental workload is high, will appear when people are trying to fight to remain awake and handle critical tasks infrequently. Such a situation occurs every night in air traffic control centres, petro-chemical plants, power plants, and in aircraft cruising long distances. These situations typically involve low activity characterised by occasional monitoring and handling of infrequent critical events. To maintain this vigilance people must increase their efforts to remain awake, alert, and able to perform their tasks at acceptable levels.

Workload issues have been identified in several TSBC incident reports. For example, equipment failure (no radar available) and a abrupt change to (sudden squall) poor visibility rapidly increased the workload for the pilot controlling the Trans Aspiration (TSBC incident report M93W0011 – TSBC, 1993). The pilot lost his situational awareness and misidentified a buoy he used for navigation. This situation prevented the pilot from developing a correct mental map of the ship's actual location. The ship's crew could not provide the correct information since the radar was not available and none of the ship's bridge crew had been monitoring the ship's progress. The lack of available information caused the pilot to resort to a manual procedure (sighting the navigational aids by eye) in zero visibility conditions. This approach involved taking sightings from several locations in the wheelhouse, while trying to consolidate the sketchy information available. Since the alteration decision point was approaching very quickly, the pilot had to make rapid decisions to determine the ship's location and thus relied on false information to navigate.

Another case involved the Pontoporos (TSBC incident report M96L0111 – TSBC, 1996a). The pilot was navigating the ship out of port into the St. Lawrence River. Since the ship's keel was only a few feet above the channel bottom, the ship handled poorly. The manoeuvring took place a night and the pilot had to take note of several cues to ensure he knew where the ship was located in the channel. The procedure is labour intensive and requires that the pilot be able to distinguish navigational aids from several lights and landmarks. Radar is not typically used for this manoeuvre. The pilot was not aware of the amount of drift occurring, likely due to the need to sort out the confusion of lights and the fact that he chose to communicate his position and intension to VTS at a critical point in the manoeuvre. This increased workload beyond the pilot's capability.

Another situation of the effect of increased workload occurred when the OOW on the self-loading bulk carrier Paterson who was certified to conduct pilotage became overwhelmed with too many tasks as a result of combining his OOW duties with his pilotage duties (TSBC incident report M99C0003 – TSBC, 1999a). The officer relied on visual sightings of leading lights and buoys to navigate, in conjunction with the electronic charting system. The absence of a buoy and the fact that the ship was in the starboard side of the channel following a previous passing, increased the pilotage task load. Due to this increase in task load the OOW did not have time to plot the ship's progress, and consequently, confirm the ship's location in the channel, using the radar. Momentary confusion caused by the misidentification of a navigational aid, and the ship's location in the starboard side of the channel, caused the OOW to apply an incorrect procedure for the alteration, and lose precious time to make the correct alteration at the correct time.

Finally, workload issues were evident in the grounding of the Norwegian Sky passenger Vessel (TSBC incident report M99L00098 – TSBC, 1999b). The coordination of tasks was not adequate, nor were there enough officers on the bridge to handle the extra tasks introduced when non-procedural manoeuvring was required for unplanned whale watching activities. Certain critical elements of tasks were ignored while the bridge crew and the pilot attended to their normal tasks, along with additional tasks to support the manoeuvres for whale watching. Since none of the crew, nor the pilot were familiar with the use of advanced navigational aids that would have automatically handled certain parts of their main tasks, each member of the crew and the pilot surpassed their workload limits by using standard manual methods. This resulted in the crew and the pilot losing track of the ship's position during the difficult, non-standard manoeuvres.

The task of pilotage requires considerable cognitive resources sometimes continuously, such as during navigation of highly sinuous sections of the river, during docking procedures, passing other ships in narrow sections of the channel, and when entering locks and canals. There is considerable evidence that shows that tasks similar to those occurring during pilotage require skills and cognitive actions that can be sustained for only short periods of time (maximum two hours – Parasuraman, 1986; Wickens, 1999). This is why air traffic controllers must be relieved every two hours or less depending on the traffic levels. These and other studies have shown that vigilance tasks degrade significantly within 30 minutes (Temple et al., 2000) and even within 10 minutes (Grier et al., 2003). Stress and fatigue accelerate this effect, causing performance to decline even sooner (Horne et al., 1983). In narrow, sinuous portions of the river, pilots must plan and make alterations and adjustments every couple of minutes, while also monitoring the ship's position in the channel and location in the river. Parasuraman (1986) illustrates this effect as it applies to the time it takes to detect a target on a radar screen. Figure 1-4 shows the results of observations of air traffic controllers charged with the task of identifying aircraft (targets) while attending to other routine tasks. After one hour the time to detect the targets becomes much longer. This trend continues over time. This is a similar situation for pilots where the marine pilot must maintain communications with VTS, the ship's crew, and monitoring important stimuli.

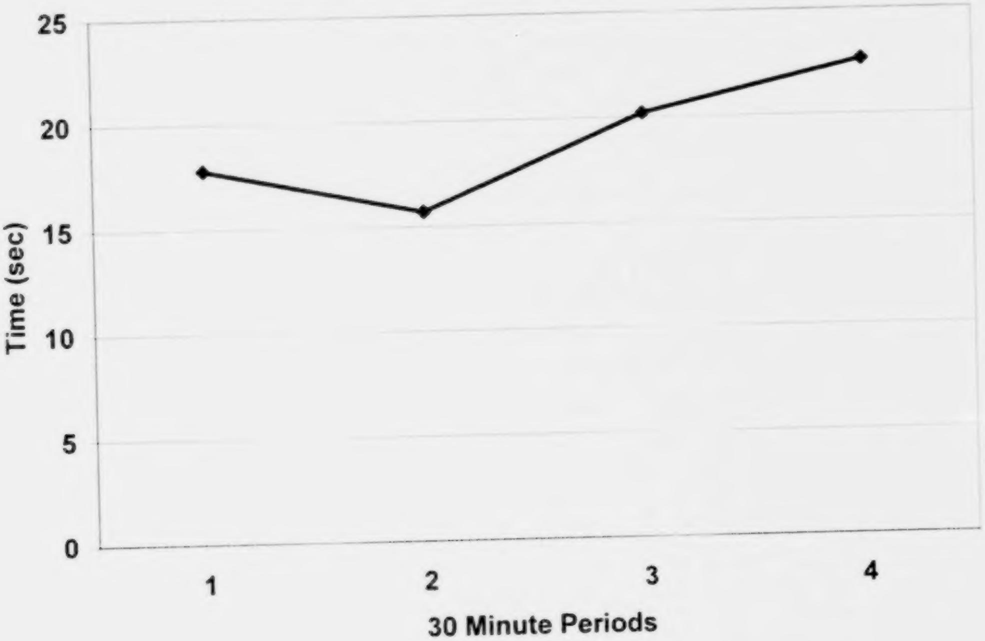


**Figure 1-4 Effect on Performance of the Amount of Time Spent on a Detection Task (from Parasuraman, 1986)**

This type of activity incurs heavy mental workload (Hockey et al., 2003), particularly in more challenging weather and river conditions. It is highly likely that pilots working in such conditions experience periods of performance decay that is below acceptable limits. That is, periods of time where vigilance must be relaxed to allow relief from the task load. These points of relaxed vigilance probably occur between alterations. However, it is also highly likely that the pilot may not be able to relax his or her vigilance and may work harder to maintain adequate vigilance and attention (as indicated by Grier et al., 2003). Since this increased workload will increase levels of fatigue (Temple et al, 2000) more substantial relief from the task may be necessary, to maintain adequate vigilance and attentional performance.

One occupational safety scientist (Berger, 1984) in Australia measured the heart rate and adrenaline levels of marine pilots and compared these data to similar data from many professions, including air traffic controllers and airline pilots. The results were that marine pilots showed higher levels of stress during normal navigation than any of the other professions. The fact that pilots regularly maintain high levels of skill while engaging in tasks that are highly stressful and fatiguing for periods of time much longer than this shows their tremendous dedication and diligence to the job. These levels will be higher in more difficult passages.

### 2.2.2 Multiple Demands on Cognitive Resources

Increased mental and physical workload will be experienced by marine pilots during busy periods, inclement weather, with crews that are less skilled, fatigued, or both, or on ships that have less than adequate equipment on board or by any combination of theses conditions. The impact on marine pilot performance when workloads approach the limits of the pilot's abilities will result in some very predicable decrements. For example, when a marine pilot must perform multiple tasks, such as talking to MTS on the radio, attending to the view of the channel through the windscreen, checking that the heading indicated is correct, and checking the radar for ship's position in the channel, the pilot will likely be at capacity. Any additional task, interruption, or change in prevailing conditions, will require that the pilot drop one or two of the existing tasks, or ignore the additional ones. This kind of cognitive resource management and the research that supports the concept is described by Wickens (1999). Another approach may include reducing the effort required for a specific task. This involves lowering standards (e.g. using less accurate or incomplete information) or truncating (e.g. leave out a step). People use strategies to lessen workload by deciding what task is most important and relevant to the situation and will consider other actions only when workload declines or the primary task is no longer necessary. This way the human operator can protect the mission by focussing on the task most relevant to the immediate goals.

These strategies include:

- Dropping tasks;
- Ignoring new tasks;
- Reducing the effort for each task.

Problems (i.e. bad outcomes) occur when the operator becomes confused, standards are critically lowered, crucial steps are omitted, or important information is missed.

Examples of this type of situation can be found in TSBC and ATSB safety reports, such as:

- TSBC safety report M95L0008 – Collision between the Ziemia Zamojska and the Cicero – helmsman did not keep ship on course ordered by pilot who was busy watching the on-coming ship pass on the port side (TSBC, 1995);
- TSBC safety report M96W0187 – Near collision between the Statendam and the Belleisle Sound/Radium 622 – Pilot was focussed on the turn which was performed using an

unfamiliar procedure, ignoring important information about oncoming traffic (TSBC, 1996b);

- TSBC safety report M96L0111 – Grounding of the Pontoporos – Pilot relied on outside visual information only to manoeuvre in fast current conditions, electing to not use radar to ascertain the ships position in the channel (TSBC, 1996b).

These are examples of focussing on a primary task without utilizing related secondary tasks to ensure good performance. The circumstances were such that the pilots were likely at the limits of their cognitive resources and could not allocate time to secondary tasks that would have helped them avoid the problem at hand. Of course, this is where effective bridge resource management should be applied either through second pilot or an OOW that is dedicated to supporting the pilot.

### 2.2.3 Positive Impact of Cognitive Resource Sharing

The sharing of cognitive tasks can sometimes be a useful strategy to reduce the mental workload that a pilot may experience during times of higher workload. This is consistent with BRM philosophy and procedures. However, this cognitive sharing must be helpful and not add to the already high mental workload existing at the time. The main criteria for determining whether cognitive tasks can be shared are:

- The cognitive task is within the experience and knowledge base of the individual accepting and performing the task;
- The secondary task (checking radar for vessel's location in the channel, verifying landmarks with the charts) is only indirectly relevant to the pilot's prime task at hand, which would be navigation (i.e. attending to navigational aids, scanning for landmarks, watching for the alignment of range lights, issuing commands, etc.,);
- The secondary task is not directly relevant to the pilot's secondary tasks that are directly relevant to the prime task of navigation (e.g. communicating with the MTS to provide a position report or checking heading indicator while monitoring the ship's progress).

Sharing of tasks can be very successful. The working relationships between the pilot and crew, or with another pilot, are more positive and effective. If the relationship is negative and uncooperative, task sharing will not be successful. Fatigue or lack of BRM training can grossly degrade communications and cooperation, preventing effective task sharing.

Examples of poor BRM contributing to marine incidents are numerous and include:

- Grounding of the Paterson (TSBC, 1999a) – the OOW was certified to pilot his own vessel but neglected to share his OOW tasks with another officer while attending to his piloting tasks, thus taking on more work than would be acceptable for effective piloting.
- Grounding of the Norwegian Sky (TSBC, 1999b) – the pilot and the crew did not co-ordinate their job tasks effectively and all neglected to monitor the ship's location relative to the shore.

- Collision between the Ziemia Zamojska and the Cicero (TSBC, 1995) – the pilot and crew were all focussed on the passing ship and did not notice that the opposing ship's passage would be too close.
- Grounding of the ANL Excellence (ATSB incident report 181). The bridge crew did not monitor the ship's passage or the pilot's actions, nor did the pilot follow his normal procedure to use his electronic charting system to verify the ship's location, given that the navigational aids were not functioning normally.

There were several other reports where poor bridge resource management was cited and where the pilot would have benefited from information that would likely have prevented the incident. Although there remains the question as to whether such information would be reliably available from the crew, the provision of that information is clearly seen as necessary to allow the pilot to perform his tasks at an acceptable level. In most of the instances cited, the ship's location according to output from the radar, an electronic charting system, or plots on the paper chart would have prevented incorrect alterations that led to the incident. This information could come from either the officer monitoring the ship's location and plotting this information on a chart every two to five minutes (depending on the frequency of the alterations), or close monitoring of the ship's location on an electronic chart or the radar. This task could be done by a ship's officer dedicated to the task of monitoring the ship's location, or another pilot.

## 2.3 Length of Time to Sustain Effective Vigilance

Vigilance is a function of a person's ability to attend to stimuli, keep track of this information, and update the information as time passes. It is affected by several factors including:

- Experience and skills of the person;
- Limitations of humans to attend to stimuli;
- The strength of the signal to noise ratio;
- Limitations of humans to monitor complex situations.

### 2.3.1 Attentional Capacity

The pilot's main concern is the safe navigation of the ship. This involves alert, constant vigilance that requires attention to information external to the ship, as well as in wheelhouse. The pilot must keep track of time to ensure that course alterations are made at the appropriate time, coincidental with the location of landmarks and navigational aids. These course alterations then must be verified by information provided by the heading and speed indicators. In conditions of darkness, poor visibility, and high traffic, the radar must be checked often. Attending to information that has this level of importance, can be tiring and the time that this type of cognitive activity can be sustained is limited. Serious degradation in sustained vigilance performance is expected to begin to occur after about 30 minutes, but is completely unacceptable after 2 hours (Parasuraman, 1986 – see Figure 1-4 above in section 2.2.1). Under good visibility and calm conditions, pilots can probably maintain reasonably acceptable vigilance performance up to 2 hours, since due to their experience and knowledge of the river may allow them to relax from the vigilance task for a few minutes during a straight portion or less critical of the river.

However, in poor visibility, strong current, ice, or high winds, the pilot will be less able to perform effective vigilance for more than less than an hour. In fact, acceptable sustained performance may be difficult to achieve for even a few minutes. It is likely, that under these conditions, pilots will have to apply strategies to alleviate their sustained attention, such as checking the radar for the vessel's position in the channel, communicating with ship's crew for verification of the ship's location and landmarks etc., or some other useful diversion. As mentioned earlier, under high workload conditions a second pilot aboard will help to reduce the fatiguing effects of the vigilance task, and will allow the pilot in control to attend to other less-demanding tasks, while someone takes over control for a while.

### 2.3.2 Impact of Attentional Capacity on Target Detection

The job of a pilot involves recognizing stimuli (targets) in amongst various conditions of obscuration to varying degrees. Range lights, landmarks, locator beacons, buoys, other vessels, and obstacles all must be discernable from the background clutter, through fog, rain, snow, and darkness. The strength in which a target is distinguishable from the background "noise" or clutter is called the signal to noise ratio. A person's ability to resolve targets against considerable clutter suffers from decay over time. If the signal to noise ratio is low (i.e. the noise is almost as prominent as the target) the decay is greater. Attending to targets in such a situation will be fatiguing and within a short time (minutes) the observer will become ineffective (Parasuraman, 1986). In poor visibility conditions, where the radar images are obscured by fog or riverbank geography is distorted by ice, outside cues will still be critical for navigation. A second pilot to relieve the pilot in control after 30 minutes to an hour will be a useful strategy to maintain acceptable performance.

One strategy that is used to reduce this decay is to sample the scene, rather than stare at it (Moray, 1986). Pilots likely do this since the ship is moving at a slow enough pace, identification of targets may be improved by sampling over a period of time to compare to other targets that may help the pilot form a mental model that is consistent with his/her understanding of the world as learned through experience. Of course there is a danger of mistakenly identifying the wrong targets and forcing a false model onto a given situation that is not true. This is when the pilot misreads the targets which he/she uses as cues for course alterations and makes a turn at the wrong spot in the channel. Having a knowledgeable second pilot aboard who is sharing the duties can help here as well.

## 2.4 Perceptual Limitations

### 2.4.1 Limitations of Human Vision

Humans have limited ability to detect light and movement, hence resolving static and dynamic images. They also have limited ability to discern an object with varying degrees of contrast against the background. Such limitations affect the pilot's ability to pick a target out against a background. Contrast and movement will be affected by dark conditions. Age will affect the pilot's ability to adapt to dark and light conditions, and the ability to focus in dark conditions (Westheimer, 1986). When working at the threshold of these limits, the eye becomes more quickly fatigued and less able to perform its functions. Furthermore, constant exposure to these conditions can result in a diminishing ability to attend to details (Parasaruman, 1986). Therefore, where the ability to detect targets is degraded by fog, river smoke, heavy snow or rain, bright lights, or other such conditions, pilots will experience diminishing effectiveness over time to the point where relief is likely necessary.

### 2.4.2 Influence of False Targets on the Development of Mental Models

Target confusion happens to pilots when they are confronted with considerable noise (background lights) or when the targets are arranged in a pattern similar to that existing in the pilot's mental model of the situation (TSBC, 1993; 1995; 1996; and 1997a). The former problem is common on the St. Lawrence, and the proliferation of lights along its banks is growing. The pilot can be distracted by these background lights and may miss important cues as to where the vessel may be located in the channel. Beacons and buoy lights may become less obvious and momentarily blend into the background clutter. Trying to focus on them can be tiring and can cause the pilot to spend more time on the task of monitoring the vessels progress through use of the outside cues, ignoring important information on radars and electronic chart displays or the heading and speed indicators. The latter problem is possibly less a problem on the St. Lawrence but is a problem nevertheless. Some landmarks and navigational aids can look very similar at times, especially in low visibility conditions. It the pilot does not check the radar or electronic chart display for the vessel's location in the channel, it is possible to mistaken them as a turn point. For ships that are less familiar with the river and on ships that are difficult to navigate in confined water, knowledge of the region will be critical. A second pilot may be a better resource to the pilot in control than the ship's crew.

## 2.5 Cognitive Aspects of Bridge Resource Management

Bridge resource management is the team management of a process. In the case of marine pilotage this involves the coordination of bridge personnel to effect safe navigation of the waters designated for pilot assistance. The addition of the pilot to the bridge team is the addition of knowledge and skills not existing in the ship's bridge team. However, the responsibility of safe passage remains with the ship's bridge officers, and ultimately with the ship's master. The bridge team must utilize the pilot's skills and knowledge as effectively as possible. This process involves concentrated cognitive task coordination. The TSBC has investigated this type of coordination and its benefits for successful navigation (TSBC, 1995). The report addresses the issue of crew staffing levels and the special nature of pilotage in very restricted conditions and the specific difficulties faced by pilots when bridge crews are not able to provide adequate support. These include the lack of knowledge that crew possess with respect to the pilotage process and the fact that ship's crews are often very fatigued. These are critical deficits in the process if pilots are to rely on a ship's bridge crew to provide adequate support.

### 2.5.1 Effective Role Allocation for Pilots and Ships' Masters

The pilot's contribution to the safe passage of the ship involves the provision of navigation directives that that bridge team must follow unless it is clear that the pilot has failed to perform his or her job tasks to an acceptable level (TSBC, 1995). This requires that the master or OOW monitor the pilot's performance and support the pilot as best as possible to ensure that the pilot meets the goals of the mission. This support consists of monitoring the ship's passage and location in the channel and providing this information to the pilot, providing the pilot with all relevant information of the ship's performance characteristics; and the bridge crew's understanding of the plan of passage followed by the pilot. It is the responsibility of the pilot to provide accurate directions to the bridge crew based on his/her knowledge of the waters, and to cooperate with the crew if he/she should fail to act upon critical information, provide incorrect direction (command), or find that he/she may require assistance. This process will be successful only if effective communications is maintained between the pilot and the bridge crew. Where conditions are such that workload for the bridge crew is abnormally high or the crew is not able to perform all of the tasks required to effectively support the pilot, than another pilot may be needed to assist. Such conditions may include serious ice build up in the channel, abnormally poor weather conditions, fast complex currents, traffic conditions that are abnormally dense, ships that push the margin of safety beyond normal piloting procedures, or ships that are carrying a payload that poses a high risk to the environment or public safety.

### 2.5.2 Importance of Communications

Bridge resource management involves the sharing of information and coordinated actions of all personnel responsible for the ship's navigation and safe passage. The effectiveness of communications is a function of the following:

- Quality of the working relationship established during the initial passage planning;
- Quality of the communication channels used (affected by language, noise, poor equipment);
- Quality of the communications procedures as written and practiced;
- Quality of the training, skills, and confidence of the pilot and bridge crewmembers;
- Level of performance, health, and well being of the pilot and the bridge crewmembers.

The personality of each person on the bridge will also have an influence on the ability to communicate with others. Training, good procedures, and positive experiences with effective BRM can improve the individual's ability to practice good communication skills. The BRM process must be seen as valuable by all if communications are to be effective.

### 2.5.3 Need for Clear Procedures

Clear BRM procedures and process is necessary for acceptance by pilots and bridge crews. Standard approaches that have been tested and tried in real working environments must be adopted. These procedures should be learned by personnel through intensive scenario-based training in high fidelity simulators, and practiced during actual voyages under the supervision of experienced trainers.

# References

Arnedt, J., Wilde, G., Munt, P., and MacLean, A. (2000) Simulated driving performance following prolonged wakefulness and alcohol consumption: separate and combined contributions to impairment. *Journal of Sleep Research*, 9:233-241.

Arnedt, J., Wilde, G., Munt, P., and MacLean, A. (2001) How do prolonged wakefulness and alcohol compare in the decrements they produce on a simulated driving task? *Accident Analysis and Prevention*, 33 (3): 47-54.

ATSB (2002) Investigation into the contact by the Russian flag container ship *Maksim Mikhaylov*. ATSB report 168.

ATSB (2002) Investigation into the grounding of the Greek registered ship *Doric Chariot*. ATSB report 182.

ATSB (2003) Investigation into the grounding of the Liberian registered container ship *ANL Excellence*. ATSB report 181.

Audet, J. and Victor, A. (1999) *Pilotage Certificate Training for Laurentian Region (District 2 Quebec City to Les Escoumins) Volume 1: Development of Program*. TP 13458E.

Audet, J. et Victor, A. (1999) Programme de formation pour l'obtention du certificat de pilotage dans la région des Laurentides, Vol.1 – Élaboration du programme.

Audet, J. et Victor, A. (1999) Programme de formation pour l'obtention du certificat de pilotage dans la région des Laurentides, Vol.2– Guide pédagogique et guide d'évaluation.

Audet, J. et Victor, A. (1999) Programme de formation pour l'obtention du certificat de pilotage dans la région des Laurentides, Vol.3– Guide d'évaluation (protégé).

Berger, Y (1984) *Port Phillip Sea Pilots: an Occupation at Risk*. PhD Thesis; Latrobe University - Australia.

Bernier (1962-70) Rapport de la Commission royale d'enquête sur le pilotage. Étude sur le pilotage au Canada.

Boivert, P. (2002) Évaluation de risques en relation avec la taille, la jauge et le type de navires canadiens assujettis au pilotage obligatoire sur le fleuve Saint-Laurent – Module 1.

Bourgeois, L.P., Cimon, P. et Larouche, L. (1998) Rapport final du comité d'étude sur le fardeau occupationnel des pilotes du Bas-Saint-Laurent.

Brander-Smith, D., Therrien, D and Tobin, S. (1990) Rapport Brander-Smith - Examen public des systèmes de sécurité des navires-citernes.

Bureau de la sécurité des transports (1995) Étude de sécurité portant sur les rapports de travail entre les capitaines et officiers de quart et les pilotes de navires.

Corporation des pilotes du Bas-Saint-Laurent (2003) Étude de risque nécessitant le double pilotage dans la circonscription no.2 de la région de l'Administration de pilotage des Laurentides.

Corporation des pilotes du Saint-Laurent central (2003) Application de la MGRP à la pratique du double pilotage dans la circonscription no.1. de la région des Laurentides.

CPSLC (2002) Analyse de risques en matière de pilotage pour la circonscription no. 1 de la région des Laurentides.

Dancosse, G. (1993) Rapport Dancosse – Étude du double pilotage pour les navires citernes et passagers et la préiode de navigation d'hiver.

Dawson, D. and Reid, K. (1997) Fatigue, alcohol and performance impairment. *Nature*, 388: 235.

Dawson, D., Roach, G., Reid, K., and Baker, A. (1997) Australian railways: shiftwork and workload analysis – final report. University of South Australia – Centre for Sleep Research.

Dawson, D. Fletcher, A. and Hussey, F. (1999) Fatigue and transport: Report to the Neville Committee. University of South Australia – Centre for Sleep Research.

DDH Environnement Ltée (2003) Analyse statistique des accidents et des incidents impliquant des navires commerciaux canadiens et étrangers survenus sur le Saint-Laurent et la rivière Saguenay.

Division du développement des voies navigables, Service à la navigation maritime de la Garde côtière canadienne (1999) Lignes directrices sur les manœuvre dans les voies navigables canadiennes; Paramètres de conception d'un chenal.

Falleti, M., Maruff, P., Collie, A., Darby, D., and Mc Stephen, M. (2003) Qualitative similarities in cognitive impairment associated with 24 h of sustained wakefulness and a blood alcohol concentration of 0.05%. *Journal of Sleep Research*, 12 (4): 265-274.

Gauthier, J. (1996) Rapport d'examen concernant les exemptions de pilotage et la certification dans la région des Laurentides.

GeoInfo Solution Ltd et Institute for risk research of Waterloo, Ontario, (1999) Méthode de conception fondée sur le risque pour les aides à la navigation sur le fleuve Saint-Laurent.

Grier, R., Warm, J., Dember, W., Matthews, G., and Galinsky, T. (2003) The vigilance decrement reflects limitations in effortful attention, not mindlessness. *Human Factors* 45 (3): 349-359.

Harrison, Y. and Horne, J. (2000) The impact of sleep deprivation on decision making: a review. *Journal of Experimental Psychology – Applied*, 6 (3): 236-249.

Hockey, G., Healey, A., Crawshaw, M., Wastell, D., and Sauer, J. (2003) Cognitive demands of collision avoidance in simulated ship control. *Human Factors* 45 (2): 252-265.

Innovation maritime (2002) Étude sur les limites de l'utilisation des cartes électroniques pour le pilotage en eaux restreintes.

Jacques, Y., Pelletier, S. et Ringuette, G. (2001) Rapport sur les essais de systèmes portatifs DGPS sur le Saint-Laurent.

Kriebel, D.L., Mayer, R.H. and Water, J.K. (1999) Impacts of navigation trends on channel usage and deseing.

LaHaye, G. (1992) Étude sur les facteurs et situation de risques en matière de pilotage – Zones de pilotage obligatoires.

Lamond, N. and Dawson, D. (1999) Quantifying the performance impairment associated with fatigue. *Journal of Sleep Research*, 8: pp. 255-262.

Luna, T.D., French, J., and Mitcha, J.L. (1997). A study of USAF air traffic controller shiftwork: Sleep, fatigue, activity, and mood analyses. *Aviation, Space, and Environmental Medicine, 68(1)*, 18-23.

Marine Safety Commitee, International Maritime Organisation (2001) Guidance on fatigue mitigation and management.

Ministère des transports (1999) Examen ministériel des questions demeurées en suspens – Rapport au Parlement.

Moray, N. (1986) Monitoring behaviour and supervisory control. In Boff, K., Kaufman, L., Thomas, J. (eds.) *Human Perception and Human Performance: Volume II*. New York; Wiley.

Parker, A. Briggs, L., Hubinger, L., Folkard, S., and Green, L. (1998) *A Survey of the Work and Sleep Patterns of Great Barrier Reef Pilots*. Canberra; Australian Maritime Safety Authority.

Parasuraman, R. (1986) Vigilance, monitoring, and search. In Boff, K., Kaufman, L., Thomas, J. (eds.) *Human Perception and Human Performance: Volume II*. New York; Wiley.

Rhodes & Associates (2003) Fatigue Management Training for Canadian Marine Pilotes. TP 14127.

Rhodes, W. and Gil, V. (2002) *Development of a Fatigue Management Program for Canadian Marine Pilots*. TDC report TP 13958E. Montreal; Transportation Development Centre.

Rhodes, W., Heslegrave, R., Ujimoto, K.V., Hahn, K., Zanon, S., Marino, A., Côté, Szlapetis, I., Pearl, S. (1996) *Impact of Shiftwork on Air Traffic Controllers, Phase II: Analysis of Shift Schedule Effects on Sleep, Performance, Physiology and Social Activities*. TP 12816E Transportation Development Centre Report.

Ricard, M. et Thériault, F. (2002) Évaluation des risques en relation avec la taille, la jauge et le type de navires canadiens assujettis au pilotage obligatoire sur le fleuve Saint-Laurent – Module 2.

Rosekind, M.R., et al. Fatigue in operational settings: Examples from the aviation environment. *Human Factors* 36 (1994): 327-338.

Shipley, P. (1978) *A Human Factors Study of Marine Pilotage*. Birbeck College.

Société linnéenne du Québec, Les Amis de la vallée du Saint-Laurent (2003) Le pilotage maritime sur le Saint-Laurent et l'analyse des risques.

Temple, J., Warm, J., Dember, W., Jones, K., Le Grange, C, and Matthews, G. (2000) The effects of signal salience and caffeine on performance, workload, and stress in an abbreviated vigilance task. Human Factors 42 (2): 183-194.

Transports Canada (1995) Document de travail sur le pilotage maritime au Canada.

Transports Canada (1995) Politique maritime nationale.

Transports Canada (1996) Loi maritime du Canada.

TSBC (1993a) *Striking by the bulk carrier "NIRJA" of the tanker "HAMILTON ENERGY".* Safety report number M93C000

TSBC (1993b) *Bottom contact of the bulk carrier "CANADIAN EXPLORER"* Safety report number M93C0001.

TSBC (1995) *A safety study of the operational relationship between ship masters/watchkeeping officers and marine pilots.* TSBC report number SM9501.

TSBC (1996) *Near-collision between the cruise ship "STATENDAM" and the tug-barge unit "BELLEISE SOUND"/"RADIUM 622", Discovery Passage, British Columbia.* Safety report number M96W0187.

TSBC (1997a) *Grounding of the bulk carrier "RAVEN ARROW".* Safety report number M97W0197.

TSBC (1997b) *Groundings of the bulk carrier "VENUS" Bécancour Harbour, St. Lawrence River, Québec.* Safety report number M97L0030.

TSBC 1997c) *Striking – oil tanker "IRVING ARCTIC" Traverse Cap-Santé, St. Lawrence River, Québec.* Safety report number M97L0019.

TSBC (1998) *Contact with bottom by bulk carrier "PACIFIC DOLPHIN" and tug "SEASPAN FALCON", Port Moody, British Columbia.* Safety report number M98W0019.

TSBC (1999a) *Grounding of the PATERSON.* Safety report M99C0003.

TSBC (1999b) *Grounding of the NORWEGIAN SKY.* Safety report M99L0098.

TSBC (2002) *A safety study of the operational relationship between ship masters/ watchkeeping officers and marine pilots.* Report SM9501, Hull; Transportation Safety Board of Canada.

Westheimer, G. (1986) The eye as an optical instrument. In Boff, K., Kaufman, L., Thomas, J. (eds.) *Human Perception and Human Performance: Volume II.* New York; Wiley.

Wickens, C. (1999) *Engineering Psychology.* Englewood Cliffs: Prentice Hall.

Williamson, A., Feyer, A., Mattick, R., Friswell, R., Finlay, S. (2001) Developing measures of fatigue using an alcohol comparison to validate the effects of fatigue on performance. ATSB, Report 189. Canberra; ATSB.

(2001) Rapport d'évaluation du navire porte-conteneurs Cast Progress.

# APPENDIX 2

# Human Error Analysis Methodology

# Human Error Analysis Methodology

# 1 INTRODUCTION

The risk assessment of double pilotage benefits from having the addition of a thorough human error analysis to support the PRMM. The human error analysis identified details of the scenarios that helped the team uncover the potential errors and their causes. Knowledge of the potential errors and causes allowed the team to consider the human elements of the risk assessment in a systematic manner. The approach added a level of investigation that was necessary to effectively understand how pilots are placed in a position to err, and determine what conditions are most likely to cause these errors. The selection of viable mitigations was made by associating them with the errors causing the greatest risk to the system. The error risk was based on their inherent frequency and the influence of error producing conditions (EPCs), ship performance characteristics, and environmental conditions. Only those mitigations that would be helpful in reducing the riskiest error modes were included. Using the information on EPCs the assessment team was able to identify a list of potential mitigations. These mitigations were discussed with the stakeholders to determine their feasibility and importance for consideration in the list of recommended mitigations. The human factors information was provided to help the stakeholders understand what the important human factors issues are, and ultimately clarify where time and money should be spent.

## 1.1 Scope and Limitations of the Analysis

### 1.1.1 Scope

The error analysis is limited to critical errors reported in TSBC safety reports and through the assessment of the types of tasks performed by pilots. Critical errors are those that could potentially lead to a catastrophic or disastrous outcome. The analysis determined the:

- Essential pilot tasks and associated error modes;
- Development of scenarios and sub-scenarios;
- Frequency of the error modes per 1,000 hours of navigation;
- Frequency of outcomes per 1,000 hours of navigation;
- Comparison of error frequency and risk between single pilot and two pilot operations.

### 1.1.2 Validity of Data

The probability of unreliability for the task data is derived from those reported by Williams (1988) who compiled the reliability data from several existing human error databases. These probabilities were verified by Kirwan et al. (1996) using a comparison to values calculated with the Technique for Human Error Rate Prediction (THERP as described in Swain and Guttmann, 1983). Field validation has been accomplished through previous applications of the HEART method (Williams, 1988) to chemical processing operations (Williams and Willey, 1988), nuclear fuel fabrication (Williams, 1988), aviation maintenance tasks (Rhodes et al., 2004), and railway occupancy control systems (Laliberte and Rhodes, 2004). Rhodes et al. (2004) found that the resulting outcome frequencies from the human error analysis were very close to those reported in the statistical records of the Transportation Safety Board of Canada (TSBC, 2000).

The Error Producing Conditions (EPCs) were derived by Williams (1988) through reviews of research and experience concerning the impact of each EPC on task performance. The estimates for the percent effect of the EPCs on the error frequencies were based on the analyst's expert opinion and information on the impact of fatigue on human performance. According to Kirwan (1997), EPC impact estimation is reasonable if determined by an expert in human error. One of the principal analysts on this project is an expert in human error and reliability (Rhodes) and was responsible for the calculation of the percent effect of the EPC values in conjunction with support from scientific research on human performance (see section 2 of Appendix 1 on the human factors issues discussed in support of the literature review).

### 1.1.3 Sources of Error Data

The data for the human error probabilities of unreliability were derived from Williams (1988). Williams obtained this data from several databases developed from the data bank created by the American Institutes for Research Data Store (Joos et. al., 1979), the Bunker-Ramo Tables (Irwin et. al., 1964), Pontecorvo (1965), and Bello and Colombari (1980).

## 1.2 General Approach

The human error analysis involved the following steps:

- Piloting tasks and subtasks were identified according to observations and formal training materials (Audet and Victor, 1999).
- Error modes were identified according to potential errors for each subtask and those identified in the literature (see Table 2-1).
- Each error mode was assigned a level of unreliability based on the types of task using the HEART method developed by Williams (1988). See Table 2-2.
- Scenarios that could potentially result in catastrophic or disastrous consequences were developed according to reports in the literature and discussions with subject matter experts (see Appendix 5).
- Event tree spreadsheets were developed to estimate the overall risk posed by each scenario.
- Event trees were created to provide a visual representation of the spreadsheet data (see Appendix 8).
- The countermeasures were identified (see Table 7 in body of report for the list of scenarios).

## Table 2-1 Human Error Listing Including Task/Error/EPC/Error Probability

| Task name, subtasks, and task elements | Generic task type | Generic Task Error Freq | Potential Error Modes | ERROR PRODUCING CONDITIONS (EPCs) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| | | | | Novel situation | Time pressure | Low signal to noise ratio | Too easy to override information or features | Data not displayed effectively | Operator model different than what designer expected | Intended action cannot be reversed | Channel capacity overload | Opposing philosophy | Need to transfer knowledge | Ambiguity in performance standards | Mismatch between perceived and real risk | Poor ambiguous system feedback | No clear confirmation of action from system | New employee | Impoverished information or person-person comm | Little or no independent checking of output | Severe fatigue |
| | | | EPC Multiplier » | 17 | 11 | 10 | 9 | 8 | 8 | 8 | 6 | 6 | 5.5 | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 3 |
| *Planning the passage* | | | | Proportional Contribution | | | | | | | | | | | | | | | | | |
| Prepare course plan | P | 0.0030 | 1. Pilot fails to obtain adequate information for plan development | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.80 | 0.00 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.20 | 0.20 |
| | P | 0.0030 | 2. Pilot prepares an inadequate plan | 0.80 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.20 | 0.20 |
| Inform the master of the specific conditions in the area | P | 0.0030 | 3. Pilot provides incorrect or misleading information to crew | 0.80 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.80 | 0.00 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.20 | 0.20 |
| | P | 0.0030 | 4. Pilot fails to provide the necessary information to crew | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.80 | 0.00 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.20 | 0.20 |
| Establish trust and confidence between the pilot and bridge watch | P | 0.0030 | 5. Pilot fails to establish trust of crew and master | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.80 | 0.00 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.20 | 0.20 |
| Evaluate ship's performance and behaviour | P | 0.0030 | 6. Pilot establishes an incorrect understanding of the ship's performance and behaviour | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.10 | 0.20 |
| | P | 0.0030 | 7. Pilot fails to evaluate ship's performance and behaviour | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.20 |
| Check instrument precision | P | 0.0030 | 8. Pilot misreads instrument and uses wrong correction factor | 0.80 | 0.10 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.20 |
| | P | 0.0030 | 9. Pilot fails to check instrument | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| Obtain information from Vessel Traffic Services (VTS) | TC | 0.0010 | 10. Pilot fails to obtain critical information from VTS | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.20 | 0.20 | 0.20 |
| | TC | 0.0010 | 11. Pilot misunderstands information from VTS | 0.80 | 0.30 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.20 | 0.20 |
| Determine the course to steer to compensate for current | TC | 0.0010 | 12. Pilot misreads information on currents and tidal points | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.20 | 0.20 |
| | TC | 0.0010 | 13. Pilot miscalculates ship's speed over ground | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.20 | 0.20 |
| | TC | 0.0010 | 14. Pilot miscalculates ship's [illegible] | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.20 | 0.20 |
| Determine time of passage in areas of greatest risk | TC | 0.0010 | 15. Pilot miscalculates the time of passage for a critical point in the transit | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| | TC | 0.0010 | 16. Pilot miscalculates effect of squat | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.20 |

## Table 2-1 continued

| Task name, subtasks, and task elements | Generic task type | Generic Task Error Freq | Potential Error Modes | ERROR PRODUCING CONDITIONS (EPCs) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| | | | | Novel situation | Time pressure | Low signal to noise ratio | Too easy to override information or features | Data not displayed effectively | Operator model different than what designer expected | Intended action cannot be reversed | Channel capacity overload | Opposing philosophy | Need to transfer knowledge | Ambiguity in performance standards | Mismatch between perceived and real risk | Poor ambiguous system feedback | No clear confirmation of action from system | New employee | Impoverished information or person-person comm. | Little or no independent checking of output | Severe fatigue |
| | | | EPC Multiplier > | 17 | 11 | 10 | 9 | 8 | 8 | 8 | 6 | 6 | 5.5 | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 3 |
| *Navigation* | | | | | | | | | | | | | | | | | | | | | |
| Check ship's position on a continuing basis | G | 0.0004 | 1. Pilot fails to check ship's position at a critical point in the transit | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.20 | 0.20 | [illegible] |
| | G | 0.0004 | 2. Pilot establishes an incorrect understanding of the ship's position | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.20 | 0.20 | [illegible] |
| Analyse information provided by the crew and Vessel Traffic Services | TC | [illegible] | 3. Pilot neglects to use VTS information | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.20 | 0.20 | [illegible] |
| Report to Vessel Traffic Services | TC | [illegible] | 4. Pilot neglects to report to VTS | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.20 | 0.20 | [illegible] |
| | TC | [illegible] | 5. Pilot provides incorrect information to VTS | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.20 | 0.20 | [illegible] |
| Give helm, steering, and engine orders | G | 0.0004 | 6. Pilot gives wrong command | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.20 | 0.20 | [illegible] |
| | G | 0.0004 | 7. Pilot fails to notice an incorrect critical action by the helmsman | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.20 | [illegible] |
| | G | 0.0004 | 8. Pilot fails to provide command at critical point in transit | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.20 | [illegible] |
| Handle the ship in accordance with weather conditions | G | 0.0004 | 9. Pilot does not adequately consider weather conditions | 0.00 | [illegible] | 0.00 | [illegible] | 0.00 | [illegible] | [illegible] | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.20 | 0.20 | [illegible] |
| Change pilots, where applicable | VC | [illegible] | 10. Pilot does not request a pilot change at appropriate location or when necessary | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| *Performing specific manoeuvres in the marine district* | | | | | | | | | | | | | | | | | | | | | |
| Perform departure and docking manoeuvres | C | [illegible] | 1. Pilot misjudges speed or direction on approach to dock | 0.00 | [illegible] | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | 0.10 | [illegible] | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0.10 | 0.00 | [illegible] |
| | VD* | [illegible] | 2. Pilot fails to follow proper procedure on leaving dock | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Perform anchoring manoeuvres | VD* | [illegible] | 3. Pilot fails to follow proper procedure while anchoring ship | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Follow instructions of the master of the icebreaker (during escort) | VD* | [illegible] | 4. Pilot fails to execute icebreaker master's instructions correctly | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | VD* | [illegible] | 5. Pilot neglects to follow icebreaker master's instructions | 0.00 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

# Table 2-1 continued

| | | | | ERROR PRODUCING CONDITIONS (EPCs) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| Task name, subtasks, and task elements | Generic task type | Generic Task Error Freq. | Potential Error Modes | Novel situation | Time pressure | Low signal to noise ratio | Too easy to override information or features | Data not displayed effectively | Operator model different than what designer expected | Intended action cannot be reversed | Channel capacity overload | Opposing philosophy | Need to transfer knowledge | Ambiguity in performance standards | Mismatch between perceived and real risk | Poor ambiguous system feedback | No clear confirmation of action from system | New employee | Impoverished information to person-person comm | Little or no independent checking of output | Severe fatigue |
| | | | EPC Multiplier = | 17 | 11 | 10 | 9 | 9 | 8 | 8 | 6 | 6 | 5.5 | 5 | 4 | 4 | 3 | 3 | 3 | 3 | 3 |
| *Performing specific manoeuvres in emergency situations* | | | | | | | | | | | | | | | | | | | | | 0.20 |
| Manoeuvres to avoid catastrophes in emergency situations | VD* | 0.1600 | 1. Pilot fails to follow proper procedure for emergency situations | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| | C | 0.1600 | 2. Pilot fails to evaluate situation in appropriate time | 0.80 | 0.10 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.20 |
| | C | 0.1600 | 3. Pilot fails to take action in appropriate time | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| | C | 0.1600 | 4. Pilot neglects to inform master of emergency situation | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| | C | 0.1600 | 5. Pilot fails to inform master in appropriate time | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| | VD* | 0.1600 | 6. Pilot fails to follow procedures for anchoring ship in emergency situation | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| | VD* | 0.1600 | 7. Pilot fails to follow procedures for grounding ship in emergency situation | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| Inform VTS of emergency situation | E | 0.0200 | 8. Pilot fails to inform VTS of emergency condition | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| Evaluate possible environmental damage | VD* | 0.1600 | 9. Pilot fails to follow proper procedure for evaluating possible environmental damage | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| | VD* | 0.1600 | 10. Pilot neglects to evaluate possible environmental damage | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.20 |
| Evaluate need for towing assistance | VD* | 0.1600 | 11. Pilot fails to follow proper procedure for evaluating need for towing service | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.20 |
| Update knowledge about emergency plans | VD* | 0.1600 | 12. Pilot fails to update knowledge about emergency plans | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.20 |
| *Ship's Crew Errors* | | | | | | | | | | | | | | | | | | | | | |
| Monitoring Pilot | I | 0.0300 | 1. OOW does not notice pilot's error | 0.80 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 | 0.20 |
| Steering Ship | E | 0.0200 | 1. Helmsman turns wheel in the incorrect direction | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 | 0.20 |
| | E | 0.0200 | 2. Helmsman turns wheel an incorrect amount | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 | 0.20 |
| Master discusses plan with pilot | I | 0.0300 | 1. Master does not engage in effective communications with the pilot | 0.00 | 0.20 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 | 0.20 |
| * VD = Violation behaviour D (Table 3 of HEART tables) | | | | | | | | | | | | | | | | | | | | | |

# Table 2-2 HEART Calculations

HEART Data Table

| Task | Task Type* Prob. | Error Modes/Task Components | EPC No. ** | EPC Effect Xs ** | Weighting of EPCs for Single Pilot | EPCs Effect with Single Pilot (with external agrevating effects) | EPCs Effect with Two Pilots | EPCs Effect with other Mitigation Mesures | Probability with Single Pilot | Probability with Two Pilots | Probability with other Mitigation mesures | Percent Increase in Risk due to Removal of Second Pilot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Planning the Passage | F | 1. Pilot fails to obtain adequate information for plan development | 1 | 17 | 0.01 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 8 | 6 | 0.25 | 1.96875 | 1 | 1.58125 | | | | |
| | 0.0030 | | 10 | 5.5 | 0.25 | 1.995625 | 1.7467188 | 1.6960625 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 39.43727312 | 4.1381274 | 22.45847815 | 0.118311819 | 0.012414382 | 0.067375434 | 853.02 |
| | | 2. Pilot prepares an inadequate plan | 1 | 17 | 0.01 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.30 | 1.48 | 1.12 | 1.36 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 11.25447279 | 2.4568302 | 8.215695977 | 0.033763418 | 0.007370491 | 0.024647088 | 358.09 |
| | | 3. Pilot provides incorrect or misleading information to crew | 1 | 17 | 0.01 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 8 | 6 | 0.25 | 1.96875 | 1 | 1.58125 | | | | |
| | | | 10 | 5.5 | 0.50 | 2.99125 | 2.4934375 | 2.792125 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.30 | 1.48 | 1.12 | 1.36 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 66.27785401 | 3.5483969 | 9.983455519 | 0.198833562 | 0.010645191 | 0.029950367 | 1767.83 |
| | | 4. Pilot fails to provide the necessary information to crew | 1 | 17 | 0.01 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 8 | 6 | 0.25 | 1.96875 | 1 | 1.58125 | | | | |
| | | | 10 | 5.5 | 0.50 | 2.99125 | 2.4934375 | 2.792125 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.30 | 1.48 | 1.12 | 1.36 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 66.27785401 | 6.1259525 | 36.27268927 | 0.198833562 | 0.018377857 | 0.108818068 | 981.92 |
| | | 5. Pilot fails to establish trust of crew and master | 1 | 17 | 0.01 | 1.16 | 1.04 | 1.16 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.68 | 3.244 | | | | |
| | | | 12 | 4 | 0.30 | 1 | 1 | 1 | | | | |
| | | | 16 | 3 | 0.10 | 1.17 | 1.085 | 1.17 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 6.639638552 | 2.0342344 | 5.462940637 | 0.019918919 | 0.006102703 | 0.016388822 | 226.40 |
| | | 6. Pilot establishes an incorrect understanding of the ship's performance and behaviour | 1 | 17 | 0.01 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 5.6749056 | 1.8748704 | 4.508173824 | 0.017024717 | 0.005624611 | 0.013524521 | 202.68 |
| | | 7. Pilot fails to evaluate ship's performance and behaviour | 1 | 17 | 0.01 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | 19 | 3 | 0.15 | 1 | 1 | 1 | | | | |
| | | | | | Overall Effect | 10.03777303 | 2.3690862 | 7.490781626 | 0.030113319 | 0.007107259 | 0.022472345 | 323.70 |
| | | 8. Pilot misreads instrument and uses wrong correction factor | 1 | 17 | 0.01 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.68 | 3.244 | | | | |
| | | | 5 | 8 | 0.20 | 2.4 | 1.7 | 2.05 | | | | |
| | | | 8 | 6 | 0.10 | 1.3875 | 1 | 1.2325 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 24.94461506 | 3.4422621 | 14.12417621 | 0.074833845 | 0.010326786 | 0.042372529 | 624.66 |
| | | 9. Pilot fails to check instrument | 1 | 17 | 0.01 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.68 | 3.244 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 5.6749056 | 1.8748704 | 4.508173824 | 0.017024717 | 0.005624611 | 0.013524521 | 202.68 |
| | TC | 10. Pilot fails to obtain critical information from VTS | 1 | 17 | 0.01 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | 0.0010 | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 56.96341435 | 4.4417297 | 33.76974565 | 0.056963414 | 0.00444173 | 0.033769746 | 1182.46 |
| | | 11. Pilot misunderstands information from VTS | 1 | 17 | 0.01 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.68 | 3.244 | | | | |
| | | | 3 | 10 | 0.20 | 2.575 | 1.7875 | 1.7875 | | | | |
| | | | 8 | 6 | 0.20 | 1.775 | 1 | 1.465 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 45.87889633 | 4.2347416 | 19.61601621 | 0.045878896 | 0.004234742 | 0.019616016 | 983.39 |
| | | 12. Pilot misreads information on currents and tidal points | 2 | 11 | 0.30 | 3.64 | 1.68 | 3.244 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 8.853252608 | 2.2779675 | 6.68819788 | 0.008853253 | 0.002277968 | 0.006688198 | 279.87 |
| | | 13. Pilot miscalculates ship's speed over ground | 2 | 11 | 0.30 | 3.64 | 1.68 | 3.244 | | | | |
| | | | 10 | 5.5 | 0.20 | 1.7965 | 1.597375 | 1.71685 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 15.54556831 | 3.6387684 | 11.48253253 | 0.046636705 | 0.003638768 | 0.011482533 | 1181.66 |
| | | 14. Pilot miscalculates ship's drift rate or direction | 2 | 11 | 0.30 | 3.64 | 1.68 | 3.244 | | | | |
| | | | 10 | 5.5 | 0.20 | 1.7965 | 1.597375 | 1.71685 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 15.54556831 | 3.6387684 | 11.48253253 | 0.015545568 | 0.003638768 | 0.011482533 | 327.22 |
| | | 15. Pilot misjudges the time of passage for a critical point in the transit | 2 | 11 | 0.30 | 3.64 | 1.68 | 3.244 | | | | |
| | | | 10 | 5.5 | 0.20 | 1.7965 | 1.597375 | 1.71685 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 8.78876544 | 2.8796838 | 6.910587705 | 0.008788765 | 0.002879684 | 0.006910588 | 205.20 |
| | | 16. Pilot misjudges effect of squat | 2 | 11 | 0.30 | 3.64 | 1.68 | 3.244 | | | | |
| | | | 10 | 5.5 | 0.20 | 1.7965 | 1.597375 | 1.71685 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 8.78876544 | 2.8796838 | 6.910587705 | 0.008788765 | 0.002879684 | 0.006910588 | 205.20 |

# Table 2-2 continued

| Task | Task Type* Prob. | Error Modes/Task Components | EPC No. ** | EPC Effect Xs ** | Weighting of EPCs for Single Pilot | EPCs Effect with Single Pilot (with external agravating effects) | EPCs Effect with Two Pilots | EPCs Effect with other Mitigation Mesures | Probability with Single Pilot | Probability with Two Pilots | Probability with other Mitigation measures | Percent Increase in Risk due to Removal of Second Pilot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Navigation | G<br>0.0004 | 1. Pilot fails to check ship's position at a critical point in the transit | 1 | 17 | 0.10 | 2.6 | 1.4 | 2.2 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 3 | 10 | 0.25 | 2.96875 | 1.984375 | 1.984375 | | | | |
| | | | 5 | 8 | 0.25 | 2.75 | 1.875 | 2.3125 | | | | |
| | | | 8 | 6 | 0.25 | 1.96875 | 1 | 1.58125 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 361.6176519 | 11.865897 | 106.7671922 | 0.144647061 | 0.004746359 | 0.042706877 | 2947.54 |
| | | 2. Pilot establishes an incorrect understanding of the ship's position | 1 | 17 | 0.10 | 2.6 | 1.4 | 2.2 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 3 | 10 | 0.25 | 2.96875 | 1.984375 | 1.984375 | | | | |
| | | | 5 | 8 | 0.25 | 2.75 | 1.875 | 2.3125 | | | | |
| | | | 8 | 6 | 0.25 | 1.96875 | 1 | 1.58125 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | 19 | 3 | 0.15 | 1 | 1 | 1 | | | | |
| | | | | | Overall Effect | 361.6176519 | 11.865897 | 106.7671922 | 0.144647061 | 0.004746359 | 0.042706877 | 2947.54 |
| | TC<br>0.0010 | 3. Pilot neglects to use VTS information | 1 | 17 | 0.10 | 2.6 | 1.4 | 2.2 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 22.49845678 | 3.1891546 | 14.71403534 | 0.022498457 | 0.003189155 | 0.014714035 | 605.47 |
| | | 4. Pilot neglects to report to VTS | 1 | 17 | 0.10 | 2.6 | 1.4 | 2.2 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 6.18089472 | 1.9211774 | 4.535769216 | 0.006180895 | 0.001921177 | 0.004535769 | 221.72 |
| | | 5. Pilot provides incorrect information to VTS | 1 | 17 | 0.10 | 2.6 | 1.4 | 2.2 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 8 | 6 | 0.20 | 1.775 | 1 | 1.465 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 4.612608 | 1.642032 | 3.3849024 | 0.004612608 | 0.001642032 | 0.003384902 | 180.91 |
| | G<br>0.0004 | 6. Pilot gives wrong command | 1 | 17 | 0.10 | 2.6 | 1.4 | 2.2 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | 19 | 3 | 0.15 | 1 | 1 | 1 | | | | |
| | | | | | Overall Effect | 22.49845678 | 3.1891546 | 14.71403534 | 0.008999183 | 0.001275662 | 0.005885614 | 605.47 |
| | | 7. Pilot fails to notice an incorrect critical action by the helmsman | 1 | 17 | 0.10 | 2.6 | 1.4 | 2.2 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 8 | 6 | 0.20 | 1.775 | 1 | 1.465 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | 19 | 3 | 0.15 | 1 | 1 | 1 | | | | |
| | | | | | Overall Effect | 39.93476079 | 3.1891546 | 21.55606177 | 0.015973904 | 0.001275662 | 0.008622425 | 1152.21 |
| | | 8. Pilot fails to provide command at critical point in transit | 1 | 17 | 0.10 | 2.6 | 1.4 | 2.2 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 8 | 6 | 0.20 | 1.775 | 1 | 1.465 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 29.80206029 | 2.7257731 | 16.08661325 | 0.011920824 | 0.001090309 | 0.006434645 | 993.34 |
| | | 9. Pilot does not adequately consider weather conditions | 1 | 17 | 0.10 | 2.6 | 1.4 | 2.2 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 3 | 10 | 0.20 | 2.575 | 1.7875 | 1.7875 | | | | |
| | | | 5 | 8 | 0.10 | 1.7 | 1.35 | 1.525 | | | | |
| | | | 8 | 6 | 0.20 | 1.775 | 1 | 1.465 | | | | |
| | | | 16 | 3 | 0.20 | 1.34 | 1.17 | 1.34 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 174.8144153 | 7.6958286 | 58.76047713 | 0.069925766 | 0.003078331 | 0.023504191 | 2171.55 |
| | VC<br>0.3800 | 10. Pilot does not request a pilot change at appropriate location or when necessary | 1 | 17 | 0.10 | 2.6 | 1.4 | 2.2 | | | | |
| | | | 2 | 11 | 0.30 | 3.64 | 1.66 | 3.244 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 12.719616 | 2.523864 | 8.85534144 | 4.83 | 0.96 | 3.37 | 403.97 |
| Performing specific manoeuvres in the marine district | C<br>0.1600 | 1. Pilot misjudges speed or direction on approach to dock | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.05 | 1.44 | 1.11 | 1.374 | | | | |
| | | | 3 | 10 | 0.05 | 1.39375 | 1.196875 | 1.196875 | | | | |
| | | | 8 | 6 | 0.05 | 1.19375 | 1 | 1.11625 | | | | |
| | | | 10 | 5.5 | 0.05 | 1.199125 | 1.1493438 | 1.1792125 | | | | |
| | | | 16 | 3 | 0.10 | 1.17 | 1.085 | 1.17 | | | | |
| | | | 17 | 3 | 0.10 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | 19 | 3 | 0.15 | 1 | 1 | 1 | | | | |
| | | | | | Overall Effect | 9.432804626 | 2.2454111 | 5.631378603 | 1.50924874 | 0.359265773 | 0.901020576 | 320.09 |
| | VD*<br>0.1800 | 2. Pilot fails to follow proper procedure on leaving dock | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.10 | 1.88 | 1.22 | 1.748 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 4.548096 | 1.589904 | 3.47026944 | 0.81865728 | 0.28618272 | 0.624548499 | 186.06 |
| | | 3. Pilot fails to follow proper procedure while anchoring ship | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.10 | 1.88 | 1.22 | 1.748 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 4.548096 | 1.589904 | 3.47026944 | 0.81865728 | 0.28618272 | 0.624548499 | 186.06 |
| | | 4. Pilot fails to execute icebreaker master's instructions correctly | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.10 | 1.88 | 1.22 | 1.748 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 4.548096 | 1.589904 | 3.47026944 | 0.81865728 | 0.28618272 | 0.624548499 | 186.06 |
| | | 5. Pilot neglects to follow icebreaker master's instructions | 1 | 11 | 0.05 | 1.5 | 1.125 | 1.375 | | | | |
| | | | 2 | 3 | 0.10 | 1.176 | 1.044 | 1.1496 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 2.370816 | 1.275507 | 1.96133256 | 0.42674688 | 0.22959126 | 0.353039861 | 85.87 |

# Table 2-2 continued

| Task | Task Type* Prob. | Error Modes/Task Components | EPC No. ** | EPC Effect Xs ** | Weighting of EPCs for Single Pilot | EPCs Effect with Single Pilot (with external agravating effects) | EPCs Effect with Two Pilots | EPCs Effect with other Mitigation Mesures | Probability with Single Pilot | Probability with Two Pilots | Probability with other Mitigation mesures | Percent Increase in Risk due to Removal of Second Pilot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Emergency situations | VD<br>0.1800 | 1. Pilot fails to follow proper procedure for emergency situations | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.10 | 1.88 | 1.22 | 1.748 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 4.548096 | 1.589904 | 3.47026944 | 0.81865728 | 0.28618272 | 0.624648499 | 186.06 |
| | C<br>0.1600 | 2. Pilot fails to evaluate situation in appropriate time | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.05 | 1.44 | 1.11 | 1.374 | | | | |
| | | | 5 | 8 | 0.05 | 1.35 | 1.175 | 1.2625 | | | | |
| | | | 8 | 6 | 0.05 | 1.19375 | 1 | 1.11625 | | | | |
| | | | 16 | 3 | 0.05 | 1.085 | 1.0425 | 1.085 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 6.091316381 | 1.7719358 | 4.170912673 | 0.97 | 0.283509726 | 0.667346028 | 243.77 |
| | | 3. Pilot fails to take action in appropriate time | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.05 | 1.44 | 1.11 | 1.374 | | | | |
| | | | 8 | 6 | 0.05 | 1.19375 | 1 | 1.11625 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 4.1586048 | 1.446552 | 3.044878531 | 0.665376768 | 0.23144832 | 0.487180565 | 187.48 |
| | | 4. Pilot neglects to inform master of emergency situation | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.05 | 1.44 | 1.11 | 1.374 | | | | |
| | | | 8 | 6 | 0.05 | 1.19375 | 1 | 1.11625 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 4.1586048 | 1.446552 | 3.044878531 | 0.665376768 | 0.23144832 | 0.487180565 | 187.48 |
| | | 5. Pilot fails to inform master in appropriate time | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.05 | 1.44 | 1.11 | 1.374 | | | | |
| | | | 8 | 6 | 0.05 | 1.19375 | 1 | 1.11625 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 4.1586048 | 1.446552 | 3.044878531 | 0.665376768 | 0.23144832 | 0.487180565 | 187.48 |
| | VD*<br>0.1800 | 6. Pilot fails to follow procedures for anchoring ship in emergency situation | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.10 | 1.88 | 1.22 | 1.748 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 4.548096 | 1.589904 | 3.47026944 | 0.81865728 | 0.28618272 | 0.624648499 | 186.06 |
| | | 7. Pilot fails to follow procedures for grounding ship in emergency situation | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.10 | 1.88 | 1.22 | 1.748 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 4.548096 | 1.589904 | 3.47026944 | 0.81865728 | 0.28618272 | 0.624648499 | 186.06 |
| | E<br>0.0200 | 8. Pilot fails to inform VTS of emergency condition | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.10 | 1.88 | 1.22 | 1.748 | | | | |
| | | | 8 | 6 | 0.10 | 1.3875 | 1 | 1.2325 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 6.3104832 | 1.589904 | 4.277107085 | 0.126208664 | 0.03179808 | 0.085542142 | 296.91 |
| | VD*<br>0.1800 | 9. Pilot fails to follow proper procedure for evaluating possible environmental damage | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.10 | 1.88 | 1.22 | 1.748 | | | | |
| | | | 8 | 6 | 0.10 | 1.3875 | 1 | 1.2325 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 6.3104832 | 1.589904 | 4.277107085 | 1.135886976 | 0.28618272 | 0.769879275 | 296.91 |
| | | 10. Pilot neglects to evaluate possible environmental damage | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.05 | 1.44 | 1.11 | 1.374 | | | | |
| | | | 8 | 6 | 0.05 | 1.19375 | 1 | 1.11625 | | | | |
| | | | 10 | 5.5 | 0.05 | 1.199125 | 1.1493438 | 1.1792125 | | | | |
| | | | 16 | 3 | 0.05 | 1.085 | 1.0425 | 1.085 | | | | |
| | | | 18 | 3 | 0.70 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 5.410555374 | 1.7332454 | 3.895756325 | 0.973889967 | 0.311984169 | 0.701236139 | 212.16 |
| | | 11. Pilot fails to follow proper procedure for evaluating need for towing service | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.05 | 1.44 | 1.11 | 1.374 | | | | |
| | | | 8 | 6 | 0.05 | 1.19375 | 1 | 1.11625 | | | | |
| | | | 10 | 5.5 | 0.05 | 1.199125 | 1.1493438 | 1.1792125 | | | | |
| | | | 16 | 3 | 0.05 | 1.085 | 1.0425 | 1.085 | | | | |
| | | | 17 | 3 | 0.20 | 1.32 | 1.08 | 1.24 | | | | |
| | | | | | Overall Effect | 5.313938314 | 1.7236694 | 3.893244554 | 0.956508897 | 0.3102606 | 0.70078402 | 208.29 |
| | | 12. Pilot fails to update knowledge about emergency plans | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.05 | 1.44 | 1.11 | 1.374 | | | | |
| | | | 8 | 6 | 0.05 | 1.19375 | 1 | 1.11625 | | | | |
| | | | 10 | 5.5 | 0.05 | 1.199125 | 1.1493438 | 1.1792125 | | | | |
| | | | 16 | 3 | 0.05 | 1.085 | 1.0425 | 1.085 | | | | |
| | | | 17 | 3 | 0.05 | 1.08 | 1.02 | 1.06 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 5.843389804 | 1.7679103 | 4.129501705 | 1.051811965 | 0.318223853 | 0.743310307 | 230.53 |
| Helmsman steers ship | G<br>0.0004 | 1. Helmsman turns wheel the incorrect direction | 2 | 11 | 0.20 | 2.76 | 1.44 | 2.496 | | | | |
| | | | 16 | 3 | 0.10 | 1.17 | 1.085 | 1.17 | | | | |
| | | | 17 | 3 | 0.10 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 5.034451968 | 1.7646371 | 4.058357023 | 0.002 | 0.001 | 0.002 | 185.30 |
| | | 2. Helmsman turns wheel an incorrect amount | 2 | 11 | 0.20 | 2.76 | 1.44 | 2.496 | | | | |
| | | | 16 | 3 | 0.10 | 1.17 | 1.085 | 1.17 | | | | |
| | | | 17 | 3 | 0.10 | 1.16 | 1.04 | 1.12 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 5.034451968 | 1.7646371 | 4.058357023 | 0.00 | 0.00 | 0.00 | 185.30 |
| Crewmember monitors pilot | G<br>0.0004 | 1. OOW fails to notice pilot's error | 1 | 17 | 0.05 | 1.8 | 1.2 | 1.6 | | | | |
| | | | 2 | 11 | 0.20 | 2.76 | 1.44 | 2.496 | | | | |
| | | | 8 | 6 | 0.05 | 1.19375 | 1 | 1.11625 | | | | |
| | | | 10 | 5.5 | 0.00 | 1 | 1 | 1 | | | | |
| | | | 16 | 3 | 0.05 | 1.085 | 1.0425 | 1.085 | | | | |
| | | | 17 | 3 | 0.05 | 1.08 | 1.02 | 1.06 | | | | |
| | | | 18 | 3 | 0.20 | 1.344 | 1.086 | 1.2408 | | | | |
| | | | | | Overall Effect | 9.340018451 | 1.9954911 | 6.361557014 | 0.003736007 | 0.000798196 | 0.002544623 | 368.06 |

* Classification of tasks based on those used by Williams (1988) for determining error rates for the HEART error analysis methodology – see HEART Table 2 for descriptions of the tasks. Frequencies for violations (e.g. VD) are derived from HEART Table 3 (VD=violation item D)

** Error Producing Conditions (EPCs) as shown in HEART Table 1

† This multiplier is based on expert opinion and involves the estimated effect fatigue has on the EPC it is applied to - note that multiplier 1.5 is the base rate suggested by Williams (1988) for fatigue

# 2 METHODS

## 2.1 Task Identification

The following tasks were identified by starting with the tasks described by Audet and Victor (1999), and modifying this list according to observations of actual piloting:

- Planning the passage;
- Navigating;
- Performing specific manoeuvres;
- Responding to emergencies.

Within each of these tasks, several subtasks were also identified. The tasks and subtasks are shown in Table 2-1. Each task is described according to each of the following:

- Task names, subtasks, and task elements;
- Generic tasks type according to Table 2-4;
- Error frequency for generic task according to Table 2-4;
- Potential error modes;
- Error producing conditions (EPCs) that affect the task;
- Multipliers and percent effect for the EPCs.

## 2.2 Identification of Major Error Modes and Levels of Unreliability

Several error modes that did and could potentially result in a catastrophic or disastrous incident were identified by reviewing TSBC safety reports and assessing what potential errors could occur for each piloting subtask and according to errors identified in the literature. These error modes are rated for their level of unreliability using the HEART method. Table 2-2 in lists these error modes and the level of unreliability these errors pose individually. The table includes:

- Task that is being performed when error may occur;
- Error modes that may occur during the performance of the task;
- Associated error producing conditions (EPCs) that may cause and influence the probability of the error's occurrence;
- Weighting to be used for each of the EPCs identified;
- Probability calculation for both single and two pilot operations; and
- Percent difference of unreliability posed by two pilots versus one.

## 2.3 Scenarios

The errors were examined in the context of scenarios developed according to information obtained through the review of incident reports and discussions with subject matter experts. These scenarios were tabulated beginning with the initiating error (event) and continuing through the enabling events to the outcome. Each event's frequency of occurrence was derived from the HEART table if the event was an error, or from technical sources if the event was weather, river, or vessel related. The scenarios (PowerPoint presentations) are contained in Appendix 5. Table 2-3 lists the scenarios used for the analysis.

**Table 2-3 List of Scenarios Used for the Assessment**

| Scenario | Hazardous Condition |
|---|---|
| Scenario 1 | Pilot incorrectly evaluates the ship's performance, draught, and manoeuvrability. |
| Scenario 2 | Pilot fails to verify the position of the ship or determines an erroneous position. |
| Scenario 3 | Pilot gives an incorrect command to crew. |
| Scenario 4 | Pilot underestimates the weather or associated navigational conditions. |
| Scenario 5 | Pilot misjudges the speed or angle of approach when docking or does not follow appropriate procedures when approaching or departing the quay. |

## 2.3 HEART Calculations

The HEART method was used to determine the error frequencies within the working environment of the pilots. The method is one of the most used human reliability methods in the UK and is one of the easiest methods to apply to the working environment. It focuses on mitigations (error reduction methods) and is based on ergonomic data and principles. The steps involved in calculating the probabilities of unreliability for each task are shown in Figure 2-1.

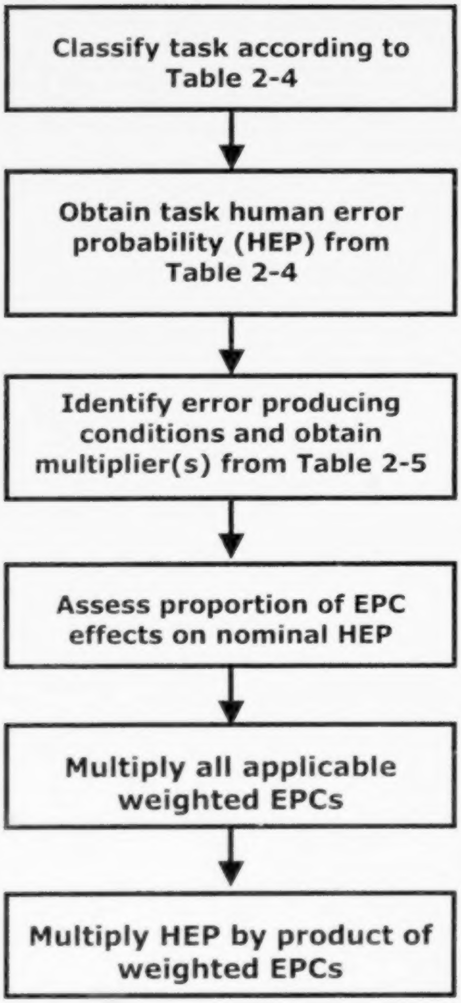

Classify task according to Table 2-4
Obtain task human error probability (HEP) from Table 2-4
Identify error producing conditions and obtain multiplier(s) from Table 2-5
Assess proportion of EPC effects on nominal HEP
Multiply all applicable weighted EPCs
Multiply HEP by product of weighted EPCs

**Figure 2-1 Process for Calculating Errors Probabilities**

### 2.3.2 Detailed Calculations

The probability calculations for Table 2-3 are derived from the combined estimated impact of applicable EPCs (derived from Table 2-5) on established levels of unreliability for types of piloting subtasks (derived from Table 2-4). The calculation for the level of unreliability for each applicable EPC, as recommended by Williams (1988), is as follows:

**Calculation of the Effect of EPCs**

The first two equations result in the weighted multiplier for each EPC and the combined effect of the EPCs that were determined to be present when the error was made.

**Equation 1 (columns H and I in Table 2-3):**

$(EPC_xW) = [(EPC_xM - 1) \times (EPC_xP) + 1]$

Where:

**$EPC_xW$** is the weighted $EPC_xM$

**$EPC_xM$** is the EPC impact multiplier.

**$EPC_xP$** is the proportion of estimated effect of the EPC on error occurrence.

"**-1**": the $EPC_xM$ is reduced by 1 to arrive at the degrees of freedom to be used for the calculation of the product of the $EPC_xM$ and $EPC_xP$.

"**+1**": The number 1 is added back to the product of the $EPC_xM$ and $EPC_xP$.

**EPCP** is determined by expert judgement using criteria that includes:

- The proportion of time that the EPC would apply to a particular situation; and
- The strength in which the EPC would influence the erroneous action.

The EPC multiplier is taken from Table 2-4.

The result in Equation 1 is an estimate for the contribution a particular EPC to the overall unreliability of a specific error mode.

The contributions of each EPC to the overall level of unreliability are multiplied together to arrive at the overall estimate of unreliability posed by a particular error mode, as shown by Equation 2:

**Equation 2 (product of the error modes' EPCs):**

$TEPC = EPC_1 \times EPC_2 \times \ldots EPC_n$

Where:

TEPC is the Total EPC Effect

The result in equation 2 gives the combined effect produced by the EPCs.

### Human Error Calculation

Equation 3 determines the error frequency of a specific error mode adjusted for the effect of the applicable EPCs.

**Equation 3 (column J in Table 3):**

$AHEP = HEP_T \times TEPC$

Where:

AHEP is the adjusted HEP for the task

$HEP_T$ is the HEP for the task obtained from Table 2-5

**Equation 4 (column L in Table 3):**

Equation 4 determines the impact of the second pilot on the frequency of the error mode's occurrence by calculating the percent increase (or decrease) of the total error frequency:

$RR = [(AHEP)_{single} - (AHEP)_{double}]/ (AHEP)_{double} X 100$

Where:

RR is the Risk Ratio for double pilotage in relation to the risk ratio for a single pilotage.

**Table 2-4 Nominal Error Probabilities for Generic Tasks**

| Generic Task | Proposed Nominal Human Unreliability ($5^{th}$ – $95^{th}$ Percentile Bounds) |
|---|---|
| A. Totally unfamiliar task, performed at speed with no real idea of likely consequence. | 0.55<br>(0.35 – 0.97) |
| B. Shift or restore system to a new or original state on a single attempt without supervision or procedure. | 0.26<br>(0.14 – 0.42) |
| C. Complex task requiring high level of comprehension and skill. | 0.16<br>(0.12 – 0.28) |
| D. Fairly simple task performed rapidly or given scant attention. | 0.09<br>(0.06 – 0.13) |
| E. Routine, highly practised, rapid task involving relatively low level of skill. | 0.02<br>(0.007 – 0.045) |
| F. Restore or shift system to a new or original state following procedures, with some checking. | 0.003<br>(0.0008 – 0.007) |
| G. Completely familiar, well designed, highly practised, routine task occurring several times per hour, performed to the highest possible standards by highly trained and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids. | 0.0004<br>(0.00008 – 0.009) |
| H. Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system state. | 0.00002<br>(0.000006 – 0.0009) |
| I. GENERIC TASK – Miscellaneous task for which no description can be found. | 0.03<br>(0.008 – 0.11) |

### 2.3.3 Use of AHEPs in Event Tree Spreadsheet Calculations

The adjusted human error probabilities (AHEPs) were assigned to each event where a human error event occurred in the event tree spreadsheet. This included both pilot errors and ship's crew errors.

## Table 2-5 Multipliers for the Error Producing Conditions (EPCs)

| Error Producing Condition | Max. Predicted Nominal Effect* |
|---|---|
| 1. Unfamiliarity with a situation, which is potentially important but which only occurs infrequently or which is novel. | x17 |
| 2. A shortage of time available for error detection and correction. | x11 |
| 3. A low signal to noise ratio. | x10 |
| 4. A means of suppressing or over-riding information or features that is too easily accessible. | x9 |
| 5. No means of conveying spatial and functional information to operators in a form that they can readily assimilate. | x8 |
| 6. A mismatch between an operator's model of the world and that imagined by the designer (or by field personnel). | x8 |
| 7. No obvious means of reversing an unintended action. | x8 |
| 8. A channel capacity overload, particularly one caused by simultaneous presentation of non-redundant information. | x6 |
| 9. A need to unlearn a technique and apply one that requires the application of an opposing philosophy. | x6 |
| 10. The need to transfer specific knowledge from task to task without loss. | x5.5 |
| 11. Ambiguity in the required performance standards. | x5 |
| 12. A mismatch between perceived and real risk. | x4 |
| 13. Poor, ambiguous or ill-matched system feedback. | x4 |
| 14. No clear direct or timely confirmation of intended action from system. | x4 |
| 15. Operator experience (e.g. a newly-qualified tradesman, but not an expert. | x3 |
| 16. An impoverished quality of information conveyed by procedures and person/person interaction. | x3 |
| 17. Little or no independent checking or testing of output. | x3 |
| 18. Fatigue that is severe enough to cause significant degradation in performance (more than 17 continuous hours awake after 8 hours of prior sleep – or poor sleep obtained over several days). | x3** |

* Maximum predicted nominal amount by which a generic task's probability of unreliability is made worse by the EPC.

** Williams (1988) did not consider severe sleep loss, only referring to work during unfavourable periods of the human circadian rhythm. This analysis considers the estimated effect of reasonable levels of sleep loss that may be experienced by most aircraft maintenance personnel working nights.

## References

1. Audet, J. and Victor, A. (1999) *Pilotage Certificate Training for Laurentian Region (District 2 Quebec City to Les Escoumins) Volume 1: Development of Program*. TP 13458E.
2. Bello, G. and Colombari, V. (1980) The human factors in risk analysis of process plants: The control room operator model "TESEO". *Reliability Engineering*, 1: pp 3-14.
3. Irwin, I., Levitz, J., and Freed, A. (1964) *Human Reliability in the Performance Of Maintenance*. Bunker-Ramo Corporation, report numbers 317-BSD-TDR-63-218 and LRP 317/TDR-63-218 – Sacromento; Aerojet-General Corporation.
4. Kirwan, B. (1996) The validation of three human reliability quantification techniques – THERP, HEART and JHEDI: Part I – Technique descriptions and validation issues. *Applied Ergonomics*, 27 (6): pp 359-373.
5. Kirwan, B. (1997) The validation of three human reliability quantification techniques – THERP, HEART and JHEDI: Part III – Practical aspects of the usage of the techniques. *Applied Ergonomics*, 28 (1): pp 27-39.
6. Kirwan, B., Scannali, S. and Robinson, L. (1996) A case study of human reliability assessment for an existing power plant. *Applied Ergonomics*, 27 (5): pp 289-302.
7. Kirwan, B., Kennedy, R., Taylor-Adams, S., and Lambert, B. (1997) The validation of three human reliability quantification techniques – THERP, HEART and JHEDI: Part II – Results of validation exercise. *Applied Ergonomics*, 28 (1): pp 17-25.
8. Pontecorvo, A. (1965) A method for human reliability. *Annals of Reliability and Maintainability*, 4: pp 337-342.
9. Swain, A. and Guttmann, H. (1983) *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*. NUREG/CR-1278 – Washington D.C.; Nuclear Regulatory Commission.
10. Williams, J. (1988) A data-based method for assessing and reducing human error to improve operational performance. *Proceedings of the IEEE Conference on Human Factors and Power Plants*, Monterey, California.

# APPENDIX 3

## Statistics Report

# Statistics Report

## 1. ANNUAL ACCIDENT RATE 1998-2001

Table 2

| Year | Trips | Number of accidents | Accident rate | Proportion of accidents in period |
|---|---|---|---|---|
| 1988 | 14 338 | 63 | 0.44% | 10.47% |
| 1989 | 12 293 | 60 | 0.49% | 9.97% |
| 1990 | 12 850 | 46 | 0.36% | 7.64% |
| 1991 | 12 232 | 49 | 0.40% | 8.14% |
| 1992 | 12 309 | 53 | 0.43% | 8.80% |
| 1993 | 11 534 | 35 | 0.30% | 5.81% |
| 1994 | 13 112 | 35 | 0.27% | 5.81% |
| 1995 | 13 042 | 52 | 0.40% | 8.64% |
| 1996 | 11 984 | 34 | 0.28% | 5.65% |
| 1997 | 11 622 | 46 | 0.40% | 7.64% |
| 1998 | 12 245 | 35 | 0.29% | 5.81% |
| 1999 | 12 455 | 37 | 0.30% | 6.15% |
| 2000 | 11 969 | 28 | 0.23% | 4.65% |
| 2001 | 11 224 | 29 | 0.26% | 4.82% |
| Total | 173 209 | 602 | 0.35% | 100.00% |

## 2(A) & 3(A) MONTHLY ACCIDENT RATES; WINTER VS. SUMMER RATES (WINTER = DEC 1 – MAR 31)

Table 4 1987 & 2002 not included

| Month | Trips (average) | Trips (total) | Number of accidents | Accident rate | Proportion of accidents in period |
|---|---|---|---|---|---|
| January | 434 | 6 076 | 54 | 0.89% | 8.97% |
| February | 358 | 5 009 | 35 | 0.70% | 5.81% |
| March | 470 | 6 582 | 24 | 0.36% | 3.99% |
| April | 964 | 13 492 | 46 | 0.34% | 7.64% |
| May | 1 269 | 17 764 | 45 | 0.25% | 7.48% |
| June | 1 374 | 19 232 | 45 | 0.23% | 7.48% |
| July | 1 442 | 20 184 | 45 | 0.22% | 7.48% |
| August | 1 401 | 19 613 | 79 | 0.40% | 13.12% |
| September | 1 304 | 18 256 | 57 | 0.31% | 9.47% |
| October | 1 279 | 17 907 | 47 | 0.26% | 7.81% |
| November | 1 177 | 16 477 | 56 | 0.34% | 9.30% |
| December | 901 | 12 617 | 69 | 0.55% | 11.46% |
| Total | 1 031 | 173 209 | 602 | 0.35% | 100.00% |

| | Trips | Number of accidents | Accident rate | Proportion of accidents in period |
|---|---|---|---|---|
| Winter | 30 284 | 182 | 0.60% | 30.23% |
| Summer | 142 925 | 420 | 0.29% | 69.77% |
| Total | 173209 | 602 | 0.35% | 100.00% |

## 2(B) AND 3(B) MONTHLY ACCIDENT RATES BY VESSEL ORIGIN; WINTER VS. SUMMER RATES BY VESSEL ORIGIN (WINTER = DEC 1 – MAR 31)

| Month | Other | | | | Canada | | | |
|---|---|---|---|---|---|---|---|---|
| | Trips | Number of accidents | Accident rate | Proportion of accidents in period | Trips | Number of accidents | Accident rate | Proportion of accidents in period |
| January | 3 226 | 34 | 1.05% | 8.99% | 2 850 | 20 | 0.70% | 8.93% |
| February | 2 804 | 23 | 0.82% | 6.08% | 2 205 | 12 | 0.54% | 5.36% |
| March | 3 475 | 16 | 0.46% | 4.23% | 3 107 | 8 | 0.26% | 3.57% |
| April | 5 908 | 30 | 0.51% | 7.94% | 7 584 | 16 | 0.21% | 7.14% |
| May | 7 106 | 31 | 0.44% | 8.20% | 10 658 | 14 | 0.13% | 6.25% |
| June | 7 036 | 31 | 0.44% | 8.20% | 12 196 | 14 | 0.11% | 6.25% |
| July | 7 382 | 31 | 0.42% | 8.20% | 12 802 | 14 | 0.11% | 6.25% |
| August | 7 395 | 42 | 0.57% | 11.11% | 12 218 | 37 | 0.30% | 16.52% |
| September | 7 287 | 34 | 0.47% | 8.99% | 10 969 | 23 | 0.21% | 10.27% |
| October | 7 619 | 29 | 0.38% | 7.67% | 10 288 | 18 | 0.17% | 8.04% |
| November | 7 668 | 31 | 0.40% | 8.20% | 8 809 | 25 | 0.28% | 11.16% |
| December | 6 075 | 46 | 0.76% | 12.17% | 6 542 | 23 | 0.35% | 10.27% |
| Total | 72 981 | 378 | 0.52% | 100.00% | 100 228 | 224 | 0.22% | 100.00% |

| Season | Other | | | | Canada | | | |
|---|---|---|---|---|---|---|---|---|
| | Trips | Number of accidents | Accident rate | Proportion of accidents in period | Trips | Number of accidents | Accident rate | Proportion of accidents in period |
| Winter | 15 580 | 119 | 0.76% | 31.48% | 14 704 | 63 | 0.43% | 28.13% |
| Summer | 57 401 | 259 | 0.45% | 68.52% | 85 524 | 161 | 0.19% | 71.88% |
| Total | 72 981 | 378 | 0.52% | 100.00% | 100228 | 224 | 0.22% | 100.00% |

The accident rate is higher in winter than in summer even though the number of accidents is higher in summer (topic discussed in the main report). The accident rate for Canadian vessels is lower than the rate for foreign vessels. However, the difference is there in summer as well as in winter, so the problems with foreign vessels should not be linked to their presence in winter.

## 4. DISTRIBUTION OF EVENTS BY TIME OF DAY

1987 and 2002 not included

Table 5

| Accidents by time of day | | |
|---|---|---|
| Time | Number of accidents | Proportion of accidents over a day |
| 0 | 14 | 2.39% |
| 1 | 16 | 2.73% |
| 2 | 30 | 5.12% |
| 3 | 28 | 4.78% |
| 4 | 16 | 2.73% |
| 5 | 8 | 1.37% |
| 6 | 13 | 2.22% |
| 7 | 20 | 3.41% |
| 8 | 21 | 3.58% |
| 9 | 23 | 3.92% |
| 10 | 23 | 3.92% |
| 11 | 28 | 4.78% |
| 12 | 31 | 5.29% |
| 13 | 17 | 2.90% |
| 14 | 48 | 8.19% |
| 15 | 33 | 5.63% |
| 16 | 25 | 4.27% |
| 17 | 35 | 5.97% |
| 18 | 24 | 4.10% |
| 19 | 26 | 4.44% |
| 20 | 24 | 4.10% |
| 21 | 30 | 5.12% |
| 22 | 27 | 4.61% |
| 23 | 26 | 4.44% |
| Total | 586 | 100.00% |

16 values missing

## 5. ACCIDENT RATES FOR THE 30 VESSEL LENGTH CLASSES

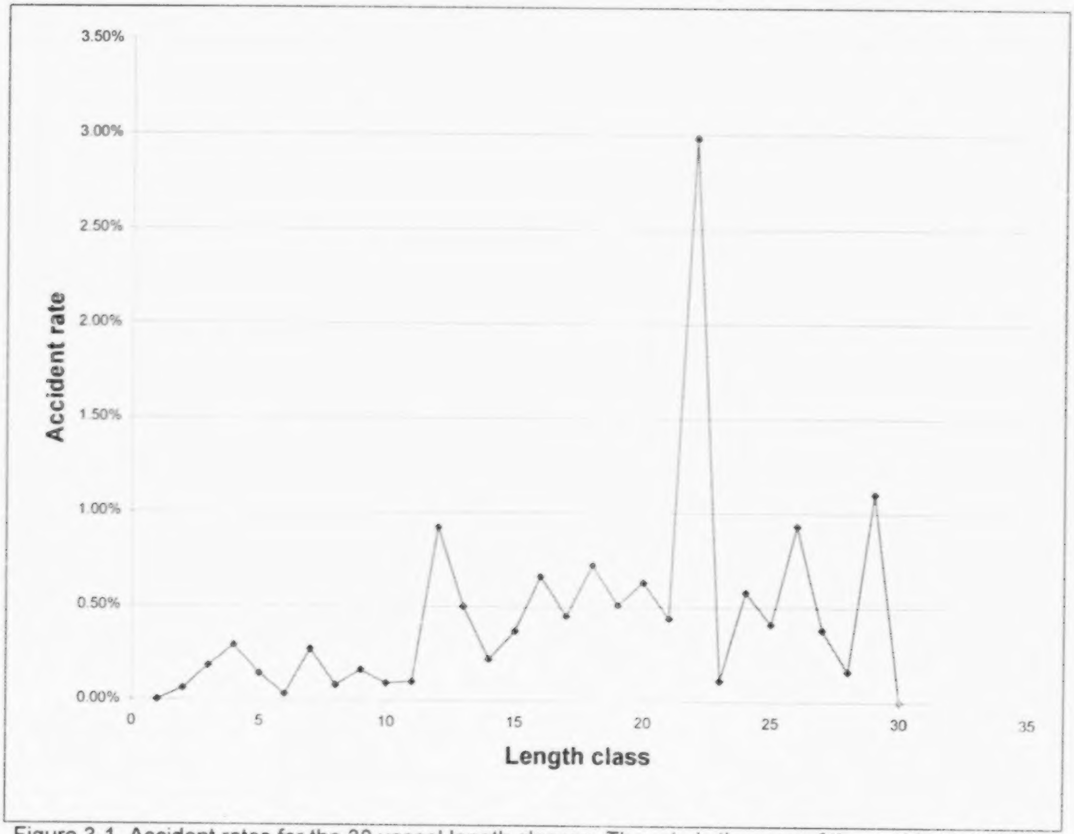


Figure 3-1. Accident rates for the 30 vessel length classes. The rate is the sum of the accidents over the sum of trips of all vessels in the length class.

As can be seen, there is a tendency for the accident rate to increase as the vessel length increases. However, for the length classes 12 and over, the rate appears to be stable (except for class 22, where the rate is extremely high).

Two possible explanations:

Use of a second pilot prevents the accident rate from continuing to rise with vessel length; or

After a certain length is reached, the accident rate is inherently stable and adding a second pilot is pointless.

To decide which of these is right, it would be necessary to be able to estimate the accident rate for long vessels when only one pilot is aboard.

## 6. ACCIDENT RATE BY LENGTH CLASS

1987 and 2002 not included

Table 6

| Accidents by length class | | | | |
|---|---|---|---|---|
| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| unknown | 197 | 24 | 12.18% | 3.99% |
| 0-09 | 666 | 0 | 0.00% | 0.00% |
| 10-19 | 8 032 | 5 | 0.06% | 0.83% |
| 20-29 | 10 641 | 19 | 0.18% | 3.16% |
| 30-39 | 9 737 | 28 | 0.29% | 4.65% |
| 40-49 | 5 567 | 8 | 0.14% | 1.33% |
| 50-59 | 16 550 | 5 | 0.03% | 0.83% |
| 60-69 | 1 865 | 5 | 0.27% | 0.83% |
| 70-79 | 1 261 | 1 | 0.08% | 0.17% |
| 80-89 | 3 694 | 6 | 0.16% | 1.00% |
| 90-99 | 8 197 | 7 | 0.09% | 1.16% |
| 100-109 | 4 030 | 4 | 0.10% | 0.66% |
| 110-119 | 2 839 | 26 | 0.92% | 4.32% |
| 120-129 | 8 016 | 40 | 0.50% | 6.64% |
| 130-139 | 10 334 | 23 | 0.22% | 3.82% |
| 140-149 | 6 700 | 25 | 0.37% | 4.15% |
| 150-159 | 6 034 | 40 | 0.66% | 6.64% |
| 160-169 | 6 645 | 30 | 0.45% | 4.98% |
| 170-179 | 10 383 | 75 | 0.72% | 12.46% |
| 180-189 | 11 442 | 58 | 0.51% | 9.63% |
| 190-199 | 5 737 | 36 | 0.63% | 5.98% |
| 200-209 | 3 209 | 14 | 0.44% | 2.33% |
| 210-219 | 2 450 | 73 | 2.98% | 12.13% |
| 220-229 | 24 044 | 27 | 0.11% | 4.49% |
| 230-239 | 1 910 | 11 | 0.58% | 1.83% |
| 240-249 | 1 465 | 6 | 0.41% | 1.00% |
| 250-259 | 215 | 2 | 0.93% | 0.33% |
| 260-269 | 524 | 2 | 0.38% | 0.33% |
| 270-279 | 632 | 1 | 0.16% | 0.17% |
| 280-289 | 91 | 1 | 1.10% | 0.17% |
| 290- + | 102 | 0 | 0.00% | 0.00% |
| Total | 173 209 | 602 | 0.35% | 100.00% |

## 7. ACCIDENT RATE BY LENGTH CLASS AND MONTH

1987 and 2002 not included

| Accidents by length class and month | | | | |
|---|---|---|---|---|
| January | | | | |
| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| unknown | 1 | 0 | 0.00% | 0.00% |
| 0-09 | 1 | 0 | 0.00% | 0.00% |
| 10-19 | 25 | 0 | 0.00% | 0.00% |
| 20-29 | 137 | 1 | 0.73% | 1.85% |
| 30-39 | 277 | 7 | 2.53% | 12.96% |
| 40-49 | 26 | 2 | 7.69% | 3.70% |
| 50-59 | 215 | 0 | 0.00% | 0.00% |
| 60-69 | 46 | 0 | 0.00% | 0.00% |
| 70-79 | 60 | 0 | 0.00% | 0.00% |
| 80-89 | 508 | 0 | 0.00% | 0.00% |
| 90-99 | 413 | 0 | 0.00% | 0.00% |
| 100-109 | 71 | 0 | 0.00% | 0.00% |
| 110-119 | 98 | 3 | 3.06% | 5.56% |
| 120-129 | 541 | 5 | 0.92% | 9.26% |
| 130-139 | 746 | 1 | 0.13% | 1.85% |
| 140-149 | 318 | 4 | 1.26% | 7.41% |
| 150-159 | 307 | 5 | 1.63% | 9.26% |
| 160-169 | 429 | 6 | 1.40% | 11.11% |
| 170-179 | 452 | 5 | 1.11% | 9.26% |
| 180-189 | 303 | 2 | 0.66% | 3.70% |
| 190-199 | 280 | 3 | 1.07% | 5.56% |
| 200-209 | 126 | 2 | 1.59% | 3.70% |
| 210-219 | 99 | 4 | 4.04% | 7.41% |
| 220-229 | 238 | 1 | 0.42% | 1.85% |
| 230-239 | 150 | 2 | 1.33% | 3.70% |
| 240-249 | 95 | 1 | 1.05% | 1.85% |
| 250-259 | 16 | 0 | 0.00% | 0.00% |
| 260-269 | 38 | 0 | 0.00% | 0.00% |
| 270-279 | 48 | 0 | 0.00% | 0.00% |
| 280-289 | 6 | 0 | 0.00% | 0.00% |
| 290- + | 6 | 0 | 0.00% | 0.00% |
| Total | 6 076 | 54 | 0.89% | 100.00% |

1987 and 2002 not included

| Accidents by length class and month | | | | |
|---|---|---|---|---|
| February | | | | |
| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Unknown | 4 | 1 | 25.00% | 2.86% |
| 0-09 | 1 | 0 | 0.00% | 0.00% |
| 10-19 | 8 | 0 | 0.00% | 0.00% |
| 20-29 | 186 | 0 | 0.00% | 0.00% |
| 30-39 | 179 | 3 | 1.68% | 8.57% |
| 40-49 | 24 | 0 | 0.00% | 0.00% |
| 50-59 | 192 | 0 | 0.00% | 0.00% |
| 60-69 | 24 | 0 | 0.00% | 0.00% |
| 70-79 | 12 | 0 | 0.00% | 0.00% |
| 80-89 | 368 | 0 | 0.00% | 0.00% |
| 90-99 | 309 | 0 | 0.00% | 0.00% |
| 100-109 | 45 | 0 | 0.00% | 0.00% |
| 110-119 | 78 | 2 | 2.56% | 5.71% |
| 120-129 | 444 | 5 | 1.13% | 14.29% |
| 130-139 | 622 | 6 | 0.96% | 17.14% |
| 140-149 | 292 | 1 | 0.34% | 2.86% |
| 150-159 | 264 | 3 | 1.14% | 8.57% |
| 160-169 | 362 | 2 | 0.55% | 5.71% |
| 170-179 | 402 | 2 | 0.50% | 5.71% |
| 180-189 | 299 | 1 | 0.33% | 2.86% |
| 190-199 | 188 | 1 | 0.53% | 2.86% |
| 200-209 | 105 | 3 | 2.86% | 8.57% |
| 210-219 | 93 | 0 | 0.00% | 0.00% |
| 220-229 | 201 | 3 | 1.49% | 8.57% |
| 230-239 | 121 | 0 | 0.00% | 0.00% |
| 240-249 | 83 | 1 | 1.20% | 2.86% |
| 250-259 | 7 | 0 | 0.00% | 0.00% |
| 260-269 | 39 | 1 | 2.56% | 2.86% |
| 270-279 | 48 | 0 | 0.00% | 0.00% |
| 280-289 | 4 | 0 | 0.00% | 0.00% |
| 290- + | 5 | 0 | 0.00% | 0.00% |
| Total | 5 009 | 35 | 0.70% | 100.00% |

1987 and 2002 not included

| Accidents by length class and month | | | | |
|---|---|---|---|---|
| March | | | | |
| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Unknown | 2 | 1 | 50.00% | 4.17% |
| 0-09 | 1 | 0 | 0.00% | 0.00% |
| 10-19 | 40 | 0 | 0.00% | 0.00% |
| 20-29 | 437 | 1 | 0.23% | 4.17% |
| 30-39 | 241 | 1 | 0.41% | 4.17% |
| 40-49 | 33 | 0 | 0.00% | 0.00% |
| 50-59 | 254 | 0 | 0.00% | 0.00% |
| 60-69 | 62 | 0 | 0.00% | 0.00% |
| 70-79 | 41 | 0 | 0.00% | 0.00% |
| 80-89 | 349 | 0 | 0.00% | 0.00% |
| 90-99 | 295 | 0 | 0.00% | 0.00% |
| 100-109 | 118 | 1 | 0.85% | 4.17% |
| 110-119 | 123 | 0 | 0.00% | 0.00% |
| 120-129 | 515 | 3 | 0.58% | 12.50% |
| 130-139 | 728 | 3 | 0.41% | 12.50% |
| 140-149 | 357 | 2 | 0.56% | 8.33% |
| 150-159 | 315 | 2 | 0.63% | 8.33% |
| 160-169 | 409 | 1 | 0.24% | 4.17% |
| 170-179 | 504 | 2 | 0.40% | 8.33% |
| 180-189 | 402 | 2 | 0.50% | 8.33% |
| 190-199 | 218 | 0 | 0.00% | 0.00% |
| 200-209 | 139 | 1 | 0.72% | 4.17% |
| 210-219 | 117 | 1 | 0.85% | 4.17% |
| 220-229 | 512 | 1 | 0.20% | 4.17% |
| 230-239 | 142 | 1 | 0.70% | 4.17% |
| 240-249 | 100 | 0 | 0.00% | 0.00% |
| 250-259 | 26 | 0 | 0.00% | 0.00% |
| 260-269 | 38 | 1 | 2.63% | 4.17% |
| 270-279 | 49 | 0 | 0.00% | 0.00% |
| 280-289 | 4 | 0 | 0.00% | 0.00% |
| 290- + | 11 | 0 | 0.00% | 0.00% |
| Total | 6 582 | 24 | 0.36% | 100.00% |

1987 and 2002 not included

| Accidents by length class and month | | | | |
|---|---|---|---|---|
| April | | | | |
| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Unknown | 15 | 3 | 20.00% | 6.52% |
| 0-09 | 38 | 0 | 0.00% | 0.00% |
| 10-19 | 539 | 0 | 0.00% | 0.00% |
| 20-29 | 726 | 2 | 0.28% | 4.35% |
| 30-39 | 525 | 0 | 0.00% | 0.00% |
| 40-49 | 309 | 1 | 0.32% | 2.17% |
| 50-59 | 694 | 0 | 0.00% | 0.00% |
| 60-69 | 170 | 0 | 0.00% | 0.00% |
| 70-79 | 150 | 1 | 0.67% | 2.17% |
| 80-89 | 366 | 0 | 0.00% | 0.00% |
| 90-99 | 610 | 0 | 0.00% | 0.00% |
| 100-109 | 347 | 0 | 0.00% | 0.00% |
| 110-119 | 207 | 1 | 0.48% | 2.17% |
| 120-129 | 654 | 3 | 0.46% | 6.52% |
| 130-139 | 911 | 2 | 0.22% | 4.35% |
| 140-149 | 544 | 1 | 0.18% | 2.17% |
| 150-159 | 566 | 5 | 0.88% | 10.87% |
| 160-169 | 647 | 3 | 0.46% | 6.52% |
| 170-179 | 840 | 6 | 0.71% | 13.04% |
| 180-189 | 921 | 4 | 0.43% | 8.70% |
| 190-199 | 486 | 5 | 1.03% | 10.87% |
| 200-209 | 279 | 0 | 0.00% | 0.00% |
| 210-219 | 176 | 8 | 4.55% | 17.39% |
| 220-229 | 2 365 | 1 | 0.04% | 2.17% |
| 230-239 | 161 | 0 | 0.00% | 0.00% |
| 240-249 | 117 | 0 | 0.00% | 0.00% |
| 250-259 | 24 | 0 | 0.00% | 0.00% |
| 260-269 | 41 | 0 | 0.00% | 0.00% |
| 270-279 | 46 | 0 | 0.00% | 0.00% |
| 280-289 | 8 | 0 | 0.00% | 0.00% |
| 290- + | 10 | 0 | 0.00% | 0.00% |
| Total | 13 492 | 46 | 0.34% | 100.00% |

1987 and 2002 not included

| Accidents by length class and month | | | | |
|---|---|---|---|---|
| May | | | | |
| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Unknown | 29 | 0 | 0.00% | 0.00% |
| 0-09 | 144 | 0 | 0.00% | 0.00% |
| 10-19 | 1 054 | 0 | 0.00% | 0.00% |
| 20-29 | 1 177 | 2 | 0.17% | 4.44% |
| 30-39 | 983 | 2 | 0.20% | 4.44% |
| 40-49 | 502 | 0 | 0.00% | 0.00% |
| 50-59 | 1 717 | 1 | 0.06% | 2.22% |
| 60-69 | 147 | 0 | 0.00% | 0.00% |
| 70-79 | 90 | 0 | 0.00% | 0.00% |
| 80-89 | 292 | 0 | 0.00% | 0.00% |
| 90-99 | 813 | 1 | 0.12% | 2.22% |
| 100-109 | 376 | 1 | 0.27% | 2.22% |
| 110-119 | 289 | 3 | 1.04% | 6.67% |
| 120-129 | 816 | 5 | 0.61% | 11.11% |
| 130-139 | 852 | 2 | 0.23% | 4.44% |
| 140-149 | 692 | 0 | 0.00% | 0.00% |
| 150-159 | 501 | 3 | 0.60% | 6.67% |
| 160-169 | 660 | 4 | 0.61% | 8.89% |
| 170-179 | 1 039 | 5 | 0.48% | 11.11% |
| 180-189 | 1 188 | 2 | 0.17% | 4.44% |
| 190-199 | 580 | 4 | 0.69% | 8.89% |
| 200-209 | 360 | 0 | 0.00% | 0.00% |
| 210-219 | 241 | 3 | 1.24% | 6.67% |
| 220-229 | 2 771 | 5 | 0.18% | 11.11% |
| 230-239 | 163 | 0 | 0.00% | 0.00% |
| 240-249 | 152 | 0 | 0.00% | 0.00% |
| 250-259 | 29 | 1 | 3.45% | 2.22% |
| 260-269 | 52 | 0 | 0.00% | 0.00% |
| 270-279 | 41 | 0 | 0.00% | 0.00% |
| 280-289 | 7 | 1 | 14.29% | 2.22% |
| 290- + | 7 | 0 | 0.00% | 0.00% |
| Total | 17 764 | 45 | 0.25% | 100.00% |

1987 and 2002 not included

Accidents by length class and month

June

| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
|---|---|---|---|---|
| Unknown | 14 | 4 | 28.57% | 8.89% |
| 0-09 | 80 | 0 | 0.00% | 0.00% |
| 10-19 | 1 198 | 0 | 0.00% | 0.00% |
| 20-29 | 1 369 | 1 | 0.07% | 2.22% |
| 30-39 | 1 323 | 2 | 0.15% | 4.44% |
| 40-49 | 994 | 0 | 0.00% | 0.00% |
| 50-59 | 2 571 | 0 | 0.00% | 0.00% |
| 60-69 | 245 | 1 | 0.41% | 2.22% |
| 70-79 | 132 | 0 | 0.00% | 0.00% |
| 80-89 | 224 | 0 | 0.00% | 0.00% |
| 90-99 | 830 | 0 | 0.00% | 0.00% |
| 100-109 | 424 | 0 | 0.00% | 0.00% |
| 110-119 | 313 | 0 | 0.00% | 0.00% |
| 120-129 | 713 | 3 | 0.42% | 6.67% |
| 130-139 | 933 | 1 | 0.11% | 2.22% |
| 140-149 | 634 | 5 | 0.79% | 11.11% |
| 150-159 | 600 | 5 | 0.83% | 11.11% |
| 160-169 | 562 | 0 | 0.00% | 0.00% |
| 170-179 | 917 | 2 | 0.22% | 4.44% |
| 180-189 | 1 073 | 6 | 0.56% | 13.33% |
| 190-199 | 619 | 1 | 0.16% | 2.22% |
| 200-209 | 278 | 3 | 1.08% | 6.67% |
| 210-219 | 246 | 6 | 2.44% | 13.33% |
| 220-229 | 2 564 | 4 | 0.16% | 8.89% |
| 230-239 | 141 | 1 | 0.71% | 2.22% |
| 240-249 | 116 | 0 | 0.00% | 0.00% |
| 250-259 | 16 | 0 | 0.00% | 0.00% |
| 260-269 | 42 | 0 | 0.00% | 0.00% |
| 270-279 | 48 | 0 | 0.00% | 0.00% |
| 280-289 | 7 | 0 | 0.00% | 0.00% |
| 290- + | 6 | 0 | 0.00% | 0.00% |
| Total | 19 232 | 45 | 0.23% | 100.00% |

1987 and 2002 not included

| Accidents by length class and month | | | | |
|---|---|---|---|---|
| July | | | | |
| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Unknown | 33 | 1 | 3.03% | 2.22% |
| 0-09 | 93 | 0 | 0.00% | 0.00% |
| 10-19 | 1 206 | 3 | 0.25% | 6.67% |
| 20-29 | 1 765 | 1 | 0.06% | 2.22% |
| 30-39 | 1 208 | 1 | 0.08% | 2.22% |
| 40-49 | 1 013 | 0 | 0.00% | 0.00% |
| 50-59 | 2 783 | 1 | 0.04% | 2.22% |
| 60-69 | 232 | 0 | 0.00% | 0.00% |
| 70-79 | 154 | 0 | 0.00% | 0.00% |
| 80-89 | 259 | 1 | 0.39% | 2.22% |
| 90-99 | 776 | 1 | 0.13% | 2.22% |
| 100-109 | 484 | 0 | 0.00% | 0.00% |
| 110-119 | 338 | 2 | 0.59% | 4.44% |
| 120-129 | 723 | 3 | 0.41% | 6.67% |
| 130-139 | 1 030 | 1 | 0.10% | 2.22% |
| 140-149 | 621 | 1 | 0.16% | 2.22% |
| 150-159 | 549 | 1 | 0.18% | 2.22% |
| 160-169 | 551 | 3 | 0.54% | 6.67% |
| 170-179 | 1 038 | 8 | 0.77% | 17.78% |
| 180-189 | 1 120 | 4 | 0.36% | 8.89% |
| 190-199 | 582 | 4 | 0.69% | 8.89% |
| 200-209 | 282 | 0 | 0.00% | 0.00% |
| 210-219 | 237 | 5 | 2.11% | 11.11% |
| 220-229 | 2 685 | 2 | 0.07% | 4.44% |
| 230-239 | 168 | 1 | 0.60% | 2.22% |
| 240-249 | 114 | 0 | 0.00% | 0.00% |
| 250-259 | 14 | 0 | 0.00% | 0.00% |
| 260-269 | 45 | 0 | 0.00% | 0.00% |
| 270-279 | 55 | 1 | 1.82% | 2.22% |
| 280-289 | 12 | 0 | 0.00% | 0.00% |
| 290- + | 14 | 0 | 0.00% | 0.00% |
| Total | 20 184 | 45 | 0.22% | 100.00% |

1987 and 2002 not included

| Accidents by length class and month | | | | |
|---|---|---|---|---|
| August | | | | |
| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Unknown | 15 | 5 | 33.33% | 6.33% |
| 0-09 | 84 | 0 | 0.00% | 0.00% |
| 10-19 | 1 100 | 1 | 0.09% | 1.27% |
| 20-29 | 1 357 | 4 | 0.29% | 5.06% |
| 30-39 | 1 302 | 3 | 0.23% | 3.80% |
| 40-49 | 978 | 0 | 0.00% | 0.00% |
| 50-59 | 2 771 | 1 | 0.04% | 1.27% |
| 60-69 | 222 | 2 | 0.90% | 2.53% |
| 70-79 | 170 | 0 | 0.00% | 0.00% |
| 80-89 | 192 | 1 | 0.52% | 1.27% |
| 90-99 | 912 | 1 | 0.11% | 1.27% |
| 100-109 | 447 | 0 | 0.00% | 0.00% |
| 110-119 | 357 | 6 | 1.68% | 7.59% |
| 120-129 | 694 | 3 | 0.43% | 3.80% |
| 130-139 | 916 | 0 | 0.00% | 0.00% |
| 140-149 | 658 | 3 | 0.46% | 3.80% |
| 150-159 | 642 | 3 | 0.47% | 3.80% |
| 160-169 | 567 | 5 | 0.88% | 6.33% |
| 170-179 | 1 028 | 8 | 0.78% | 10.13% |
| 180-189 | 1 119 | 10 | 0.89% | 12.66% |
| 190-199 | 539 | 4 | 0.74% | 5.06% |
| 200-209 | 299 | 3 | 1.00% | 3.80% |
| 210-219 | 235 | 13 | 5.53% | 16.46% |
| 220-229 | 2 577 | 1 | 0.04% | 1.27% |
| 230-239 | 159 | 2 | 1.26% | 2.53% |
| 240-249 | 141 | 0 | 0.00% | 0.00% |
| 250-259 | 19 | 0 | 0.00% | 0.00% |
| 260-269 | 40 | 0 | 0.00% | 0.00% |
| 270-279 | 59 | 0 | 0.00% | 0.00% |
| 280-289 | 8 | 0 | 0.00% | 0.00% |
| 290- + | 6 | 0 | 0.00% | 0.00% |
| Total | 19 613 | 79 | 0.40% | 100.00% |

*1987 and 2002 not included*

Accidents by length class and month

September

| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
|---|---|---|---|---|
| Unknown | 33 | 2 | 6.06% | 3.51% |
| 0-09 | 47 | 0 | 0.00% | 0.00% |
| 10-19 | 1 115 | 0 | 0.00% | 0.00% |
| 20-29 | 1 024 | 1 | 0.10% | 1.75% |
| 30-39 | 1 215 | 3 | 0.25% | 5.26% |
| 40-49 | 699 | 2 | 0.29% | 3.51% |
| 50-59 | 2 309 | 1 | 0.04% | 1.75% |
| 60-69 | 213 | 0 | 0.00% | 0.00% |
| 70-79 | 140 | 0 | 0.00% | 0.00% |
| 80-89 | 253 | 1 | 0.40% | 1.75% |
| 90-99 | 904 | 0 | 0.00% | 0.00% |
| 100-109 | 467 | 0 | 0.00% | 0.00% |
| 110-119 | 271 | 2 | 0.74% | 3.51% |
| 120-129 | 649 | 2 | 0.31% | 3.51% |
| 130-139 | 847 | 1 | 0.12% | 1.75% |
| 140-149 | 619 | 2 | 0.32% | 3.51% |
| 150-159 | 586 | 3 | 0.51% | 5.26% |
| 160-169 | 546 | 2 | 0.37% | 3.51% |
| 170-179 | 1 004 | 7 | 0.70% | 12.28% |
| 180-189 | 1 159 | 3 | 0.26% | 5.26% |
| 190-199 | 546 | 4 | 0.73% | 7.02% |
| 200-209 | 346 | 1 | 0.29% | 1.75% |
| 210-219 | 232 | 11 | 4.74% | 19.30% |
| 220-229 | 2 511 | 4 | 0.16% | 7.02% |
| 230-239 | 197 | 2 | 1.02% | 3.51% |
| 240-249 | 177 | 2 | 1.13% | 3.51% |
| 250-259 | 19 | 1 | 5.26% | 1.75% |
| 260-269 | 49 | 0 | 0.00% | 0.00% |
| 270-279 | 57 | 0 | 0.00% | 0.00% |
| 280-289 | 15 | 0 | 0.00% | 0.00% |
| 290- + | 7 | 0 | 0.00% | 0.00% |
| Total | 18 256 | 57 | 0.31% | 100.00% |

1987 and 2002 not included

| Accidents by length class and month | | | | |
|---|---|---|---|---|
| October | | | | |
| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Unknown | 26 | 0 | 0.00% | 0.00% |
| 0-09 | 102 | 0 | 0.00% | 0.00% |
| 10-19 | 937 | 1 | 0.11% | 2.13% |
| 20-29 | 1 056 | 4 | 0.38% | 8.51% |
| 30-39 | 1 063 | 3 | 0.28% | 6.38% |
| 40-49 | 468 | 1 | 0.21% | 2.13% |
| 50-59 | 1 584 | 1 | 0.06% | 2.13% |
| 60-69 | 209 | 0 | 0.00% | 0.00% |
| 70-79 | 123 | 0 | 0.00% | 0.00% |
| 80-89 | 226 | 1 | 0.44% | 2.13% |
| 90-99 | 818 | 3 | 0.37% | 6.38% |
| 100-109 | 496 | 1 | 0.20% | 2.13% |
| 110-119 | 314 | 3 | 0.96% | 6.38% |
| 120-129 | 774 | 1 | 0.13% | 2.13% |
| 130-139 | 947 | 1 | 0.11% | 2.13% |
| 140-149 | 655 | 2 | 0.31% | 4.26% |
| 150-159 | 592 | 2 | 0.34% | 4.26% |
| 160-169 | 614 | 1 | 0.16% | 2.13% |
| 170-179 | 1 097 | 8 | 0.73% | 17.02% |
| 180-189 | 1 314 | 5 | 0.38% | 10.64% |
| 190-199 | 599 | 1 | 0.17% | 2.13% |
| 200-209 | 385 | 0 | 0.00% | 0.00% |
| 210-219 | 288 | 3 | 1.04% | 6.38% |
| 220-229 | 2 712 | 2 | 0.07% | 4.26% |
| 230-239 | 208 | 1 | 0.48% | 2.13% |
| 240-249 | 142 | 2 | 1.41% | 4.26% |
| 250-259 | 12 | 0 | 0.00% | 0.00% |
| 260-269 | 60 | 0 | 0.00% | 0.00% |
| 270-279 | 66 | 0 | 0.00% | 0.00% |
| 280-289 | 6 | 0 | 0.00% | 0.00% |
| 290- + | 14 | 0 | 0.00% | 0.00% |
| Total | 17 907 | 47 | 0.26% | 100.00% |

1987 and 2002 not included

Accidents by length class and month

November

| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
|---|---|---|---|---|
| Unknown | 15 | 1 | 6.67% | 1.79% |
| 0-09 | 64 | 0 | 0.00% | 0.00% |
| 10-19 | 598 | 0 | 0.00% | 0.00% |
| 20-29 | 910 | 1 | 0.11% | 1.79% |
| 30-39 | 857 | 3 | 0.35% | 5.36% |
| 40-49 | 290 | 2 | 0.69% | 3.57% |
| 50-59 | 828 | 0 | 0.00% | 0.00% |
| 60-69 | 214 | 1 | 0.47% | 1.79% |
| 70-79 | 94 | 0 | 0.00% | 0.00% |
| 80-89 | 304 | 1 | 0.33% | 1.79% |
| 90-99 | 769 | 0 | 0.00% | 0.00% |
| 100-109 | 433 | 0 | 0.00% | 0.00% |
| 110-119 | 251 | 4 | 1.59% | 7.14% |
| 120-129 | 792 | 1 | 0.13% | 1.79% |
| 130-139 | 951 | 0 | 0.00% | 0.00% |
| 140-149 | 692 | 1 | 0.14% | 1.79% |
| 150-159 | 591 | 5 | 0.85% | 8.93% |
| 160-169 | 674 | 1 | 0.15% | 1.79% |
| 170-179 | 1 208 | 11 | 0.91% | 19.64% |
| 180-189 | 1 469 | 9 | 0.61% | 16.07% |
| 190-199 | 624 | 4 | 0.64% | 7.14% |
| 200-209 | 347 | 0 | 0.00% | 0.00% |
| 210-219 | 292 | 9 | 3.08% | 16.07% |
| 220-229 | 2 795 | 2 | 0.07% | 3.57% |
| 230-239 | 154 | 0 | 0.00% | 0.00% |
| 240-249 | 126 | 0 | 0.00% | 0.00% |
| 250-259 | 19 | 0 | 0.00% | 0.00% |
| 260-269 | 41 | 0 | 0.00% | 0.00% |
| 270-279 | 58 | 0 | 0.00% | 0.00% |
| 280-289 | 7 | 0 | 0.00% | 0.00% |
| 290- + | 10 | 0 | 0.00% | 0.00% |
| Total | 16 477 | 56 | 0.34% | 100.00% |

1987 and 2002 not included

| Accidents by length class and month | | | | |
|---|---|---|---|---|
| December | | | | |
| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Unknown | 10 | 6 | 60.00% | 8.70% |
| 0-09 | 11 | 0 | 0.00% | 0.00% |
| 10-19 | 212 | 0 | 0.00% | 0.00% |
| 20-29 | 497 | 1 | 0.20% | 1.45% |
| 30-39 | 564 | 0 | 0.00% | 0.00% |
| 40-49 | 231 | 0 | 0.00% | 0.00% |
| 50-59 | 632 | 0 | 0.00% | 0.00% |
| 60-69 | 81 | 1 | 1.23% | 1.45% |
| 70-79 | 95 | 0 | 0.00% | 0.00% |
| 80-89 | 353 | 1 | 0.28% | 1.45% |
| 90-99 | 748 | 1 | 0.13% | 1.45% |
| 100-109 | 322 | 1 | 0.31% | 1.45% |
| 110-119 | 200 | 0 | 0.00% | 0.00% |
| 120-129 | 701 | 6 | 0.86% | 8.70% |
| 130-139 | 851 | 5 | 0.59% | 7.25% |
| 140-149 | 618 | 3 | 0.49% | 4.35% |
| 150-159 | 521 | 3 | 0.58% | 4.35% |
| 160-169 | 624 | 2 | 0.32% | 2.90% |
| 170-179 | 854 | 11 | 1.29% | 15.94% |
| 180-189 | 1 075 | 10 | 0.93% | 14.49% |
| 190-199 | 476 | 5 | 1.05% | 7.25% |
| 200-209 | 263 | 1 | 0.38% | 1.45% |
| 210-219 | 194 | 10 | 5.15% | 14.49% |
| 220-229 | 2 113 | 1 | 0.05% | 1.45% |
| 230-239 | 146 | 1 | 0.68% | 1.45% |
| 240-249 | 102 | 0 | 0.00% | 0.00% |
| 250-259 | 14 | 0 | 0.00% | 0.00% |
| 260-269 | 39 | 0 | 0.00% | 0.00% |
| 270-279 | 57 | 0 | 0.00% | 0.00% |
| 280-289 | 7 | 0 | 0.00% | 0.00% |
| 290- + | 6 | 0 | 0.00% | 0.00% |
| Total | 12 617 | 69 | 0.55% | 100.00% |

## 8. ACCIDENT RATE BY LENGTH CLASS: SUMMER VS. WINTER

1987 and 2002 not included

| Accidents by length class (summer vs. winter) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Length class | Summer | | | | Winter | | | |
| | Trips | Number of accidents | Accident rate | Proportion of all accidents | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Unknown | 180 | 16 | 8.89% | 3.81% | 17 | 8 | 47.06% | 4.40% |
| 0-09 | 652 | 0 | 0.00% | 0.00% | 14 | 0 | 0.00% | 0.00% |
| 10-19 | 7 747 | 5 | 0.06% | 1.19% | 285 | 0 | 0.00% | 0.00% |
| 20-29 | 9 384 | 16 | 0.17% | 3.81% | 1 257 | 3 | 0.24% | 1.65% |
| 30-39 | 8 476 | 17 | 0.20% | 4.05% | 1 261 | 11 | 0.87% | 6.04% |
| 40-49 | 5 253 | 6 | 0.11% | 1.43% | 314 | 2 | 0.64% | 1.10% |
| 50-59 | 15 257 | 5 | 0.03% | 1.19% | 1 293 | 0 | 0.00% | 0.00% |
| 60-69 | 1 652 | 4 | 0.24% | 0.95% | 213 | 1 | 0.47% | 0.55% |
| 70-79 | 1 053 | 1 | 0.09% | 0.24% | 208 | 0 | 0.00% | 0.00% |
| 80-89 | 2 116 | 5 | 0.24% | 1.19% | 1 578 | 1 | 0.06% | 0.55% |
| 90-99 | 6 432 | 6 | 0.09% | 1.43% | 1 765 | 1 | 0.06% | 0.55% |
| 100-109 | 3 474 | 2 | 0.06% | 0.48% | 556 | 2 | 0.36% | 1.10% |
| 110-119 | 2 340 | 21 | 0.90% | 5.00% | 499 | 5 | 1.00% | 2.75% |
| 120-129 | 5 815 | 21 | 0.36% | 5.00% | 2 201 | 19 | 0.86% | 10.44% |
| 130-139 | 7 387 | 8 | 0.11% | 1.90% | 2 947 | 15 | 0.51% | 8.24% |
| 140-149 | 5 115 | 15 | 0.29% | 3.57% | 1 585 | 10 | 0.63% | 5.49% |
| 150-159 | 4 627 | 27 | 0.58% | 6.43% | 1 407 | 13 | 0.92% | 7.14% |
| 160-169 | 4 821 | 19 | 0.39% | 4.52% | 1 824 | 11 | 0.60% | 6.04% |
| 170-179 | 8 171 | 55 | 0.67% | 13.10% | 2 212 | 20 | 0.90% | 10.99% |
| 180-189 | 9 363 | 43 | 0.46% | 10.24% | 2 079 | 15 | 0.72% | 8.24% |
| 190-199 | 4 575 | 27 | 0.59% | 6.43% | 1 162 | 9 | 0.77% | 4.95% |
| 200-209 | 2 576 | 7 | 0.27% | 1.67% | 633 | 7 | 1.11% | 3.85% |
| 210-219 | 1 947 | 58 | 2.98% | 13.81% | 503 | 15 | 2.98% | 8.24% |
| 220-229 | 20 980 | 21 | 0.10% | 5.00% | 3 064 | 6 | 0.20% | 3.30% |
| 230-239 | 1 351 | 7 | 0.52% | 1.67% | 559 | 4 | 0.72% | 2.20% |
| 240-249 | 1 085 | 4 | 0.37% | 0.95% | 380 | 2 | 0.53% | 1.10% |
| 250-259 | 152 | 2 | 1.32% | 0.48% | 63 | 0 | 0.00% | 0.00% |
| 260-269 | 370 | 0 | 0.00% | 0.00% | 154 | 2 | 1.30% | 1.10% |
| 270-279 | 430 | 1 | 0.23% | 0.24% | 202 | 0 | 0.00% | 0.00% |
| 280-289 | 70 | 1 | 1.43% | 0.24% | 21 | 0 | 0.00% | 0.00% |
| 290- + | 74 | 0 | 0,00% | 0,00% | 28 | 0 | 0,00% | 0,00% |
| Total | 142 925 | 420 | 0.29% | 100.00% | 30 284 | 182 | 0.60% | 100.00% |

## 9. ACCIDENT RATE BY GRT CLASS

1987 and 2002 not included

| Accidents by GRT class | | | | |
|---|---|---|---|---|
| GRT class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Inconnu | 4 948 | 16 | 0.32% | 2.66% |
| 1-4999 | 67 537 | 97 | 0.14% | 16.11% |
| 5000-9999 | 23 643 | 95 | 0.40% | 15.78% |
| 10000-14999 | 15 137 | 95 | 0.63% | 15.78% |
| 15000-19999 | 34 373 | 167 | 0.49% | 27.74% |
| 20000-24999 | 15 734 | 82 | 0.52% | 13.62% |
| 25000-29999 | 2 338 | 10 | 0.43% | 1.66% |
| 30000-34999 | 3 747 | 20 | 0.53% | 3.32% |
| 35000-39999 | 2 044 | 6 | 0.29% | 1.00% |
| 40000-44999 | 1 642 | 6 | 0.37% | 1.00% |
| 45000-49999 | 262 | 1 | 0.38% | 0.17% |
| 50000-54999 | 170 | 0 | 0.00% | 0.00% |
| 55000-59999 | 204 | 1 | 0.49% | 0.17% |
| 60000-64999 | 154 | 0 | 0.00% | 0.00% |
| 65000-69999 | 110 | 0 | 0.00% | 0.00% |
| 70000-74999 | 50 | 1 | 2.00% | 0.17% |
| 75000-79999 | 154 | 2 | 1.30% | 0.33% |
| 80000-84999 | 848 | 3 | 0.35% | 0.50% |
| 85000-89999 | 6 | 0 | 0.00% | 0.00% |
| 90000- + | 108 | 0 | 0.00% | 0.00% |
| Total | 173 209 | 602 | 0.35% | 100.00% |

## 10. ACCIDENT RATE BY VESSEL TYPE

1987 and 2002 not included

| Accidents by vessel type | | | | |
|---|---|---|---|---|
| Type | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Tanker | 34 638 | 94 | 0.27% | 15.61% |
| Freighter | 28 499 | 153 | 0.54% | 25.42% |
| Passenger | 17 697 | 8 | 0.05% | 1.33% |
| Bulker | 54 958 | 289 | 0.53% | 48.01% |
| Other | 37 417 | 58 | 0.16% | 9.63% |
| Total | 173 209 | 602 | 0.35% | 100.00% |

## 11. TANKER ACCIDENT RATE BY GRT CLASS

1987 and 2002 not included

| Tanker accidents by GRT class | | | | |
|---|---|---|---|---|
| GRT class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Inconnu | 4 | 0 | 0.00% | 0.00% |
| 1-4999 | 13 298 | 14 | 0.11% | 14.89% |
| 5000-9999 | 13 987 | 48 | 0.34% | 51.06% |
| 10000-14999 | 2 128 | 11 | 0.52% | 11.70% |
| 15000-19999 | 1 301 | 6 | 0.46% | 6.38% |
| 20000-24999 | 1 359 | 9 | 0.66% | 9.57% |
| 25000-29999 | 999 | 2 | 0.20% | 2.13% |
| 30000-34999 | 259 | 0 | 0.00% | 0.00% |
| 35000-39999 | 193 | 1 | 0.52% | 1.06% |
| 40000-44999 | 137 | 0 | 0.00% | 0.00% |
| 45000-49999 | 8 | 0 | 0.00% | 0.00% |
| 50000-54999 | 94 | 0 | 0.00% | 0.00% |
| 55000-59999 | 26 | 0 | 0.00% | 0.00% |
| 60000-64999 | 22 | 0 | 0.00% | 0.00% |
| 65000-69999 | 14 | 0 | 0.00% | 0.00% |
| 70000-74999 | 8 | 0 | 0.00% | 0.00% |
| 75000-79999 | 112 | 1 | 0.89% | 1.06% |
| 80000-84999 | 683 | 2 | 0.29% | 2.13% |
| 85000-89999 | 4 | 0 | 0.00% | 0.00% |
| 90000- + | 2 | 0 | 0.00% | 0.00% |
| Total | 34 638 | 94 | 0.27% | 100.00% |

## 12. PASSENGER VESSEL ACCIDENT RATE BY LENGTH CLASS

1987 and 2002 not included

| Passenger vessel accidents by length class | | | | |
|---|---|---|---|---|
| Length class | Trips | Number of accidents | Accident rate | Proportion of all accidents |
| Unknown | 10 | 1 | 10.00% | 12.50% |
| 0-09 | 17 | 0 | 0.00% | 0.00% |
| 10-19 | 1 132 | 0 | 0.00% | 0.00% |
| 20-29 | 857 | 0 | 0.00% | 0.00% |
| 30-39 | 2 110 | 0 | 0.00% | 0.00% |
| 40-49 | 2 482 | 0 | 0.00% | 0.00% |
| 50-59 | 8 431 | 0 | 0.00% | 0.00% |
| 60-69 | 531 | 0 | 0.00% | 0.00% |
| 70-79 | 396 | 0 | 0.00% | 0.00% |
| 80-89 | 176 | 0 | 0.00% | 0.00% |
| 90-99 | 58 | 0 | 0.00% | 0.00% |
| 100-109 | 74 | 0 | 0.00% | 0.00% |
| 110-119 | 5 | 0 | 0.00% | 0.00% |
| 120-129 | 20 | 0 | 0.00% | 0.00% |
| 130-139 | 111 | 0 | 0.00% | 0.00% |
| 140-149 | 30 | 0 | 0.00% | 0.00% |
| 150-159 | 234 | 0 | 0.00% | 0.00% |
| 160-169 | 51 | 0 | 0.00% | 0.00% |
| 170-179 | 33 | 0 | 0.00% | 0.00% |
| 180-189 | 230 | 0 | 0.00% | 0.00% |
| 190-199 | 231 | 4 | 1.73% | 50.00% |
| 200-209 | 124 | 0 | 0.00% | 0.00% |
| 210-219 | 58 | 0 | 0.00% | 0.00% |
| 220-229 | 32 | 0 | 0.00% | 0.00% |
| 230-239 | 113 | 0 | 0.00% | 0.00% |
| 240-249 | 101 | 0 | 0.00% | 0.00% |
| 250-259 | 4 | 2 | 50.00% | 25.00% |
| 260-269 | 20 | 1 | 5.00% | 12.50% |
| 270-279 | 20 | 0 | 0.00% | 0.00% |
| 280-289 | 0 | 0 | / | 0.00% |
| 290- + | 6 | 0 | 0.00% | 0.00% |
| Total | 16 477 | 8 | 0.05% | 100.00% |

Because the number of accidents with this type of vessel is so small, the accident rates shown are not very reliable.

## Discussion

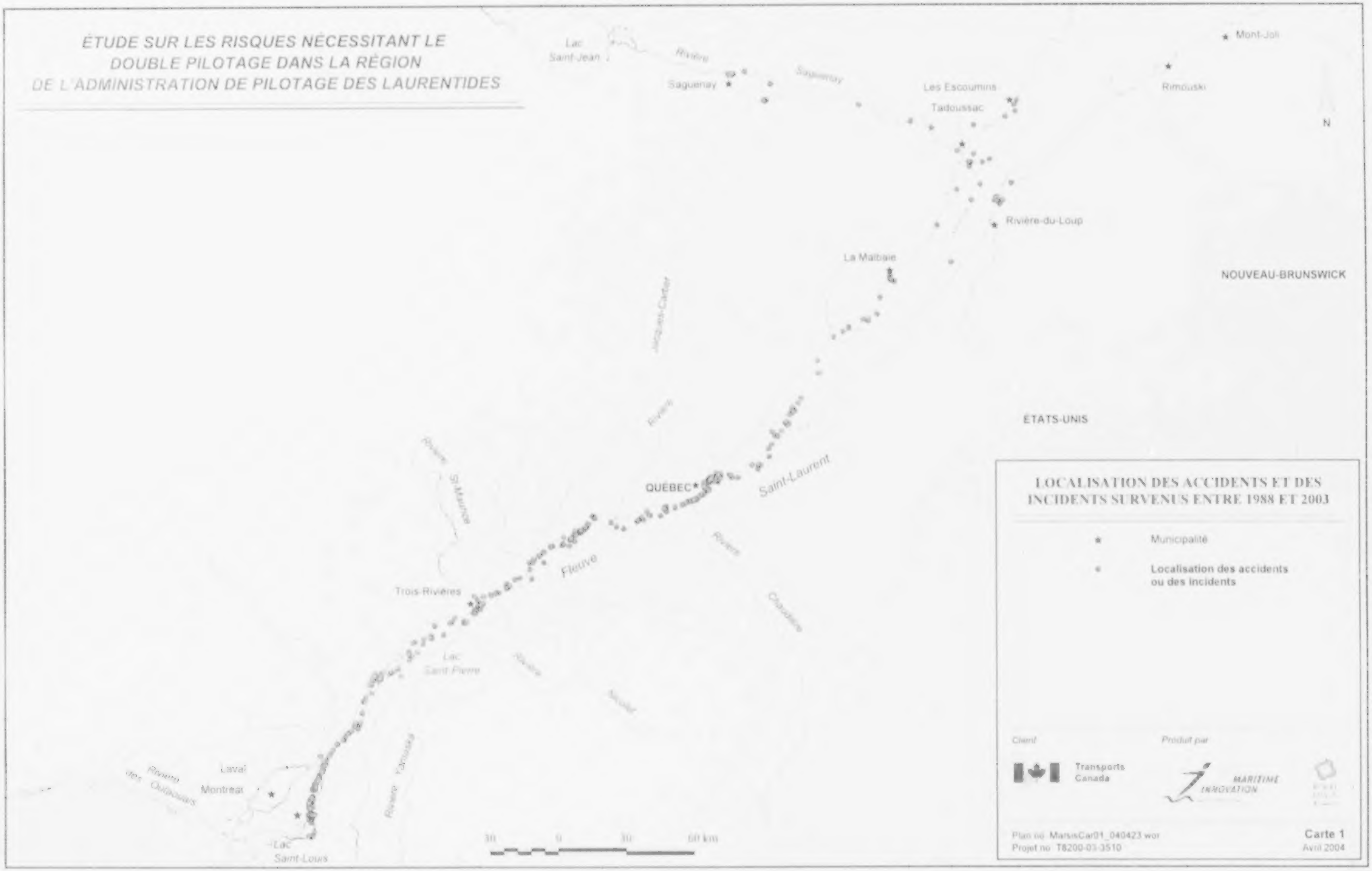
Because the lack of points of comparison is the main obstacle as regards the limitations of our analyses with respect to determining the number of pilots needed in various situations, these tables are mainly descriptive.

Nevertheless here are some thoughts.

Several tables report few accidents and therefore the accident rates shown are less reliable and they are hard to compare. For example, the tables for accidents by class length and month include several classes with 0 accidents and hardly any trips, as well as several classes with just a few trips. As a result, the rates vary greatly. The tables must therefore be interpreted with care.

# APPENDIX 4

## Spatial Analysis Maps



ÉTUDE SUR LES RISQUES NÉCESSITANT LE
DOUBLE PILOTAGE DANS LA RÉGION
DE L'ADMINISTRATION DE PILOTAGE DES LAURENTIDES

LOCALISATION DES ACCIDENTS ET DES
INCIDENTS SURVENUS ENTRE 1988 ET 2003

★ Municipalité
● Localisation des accidents ou des incidents

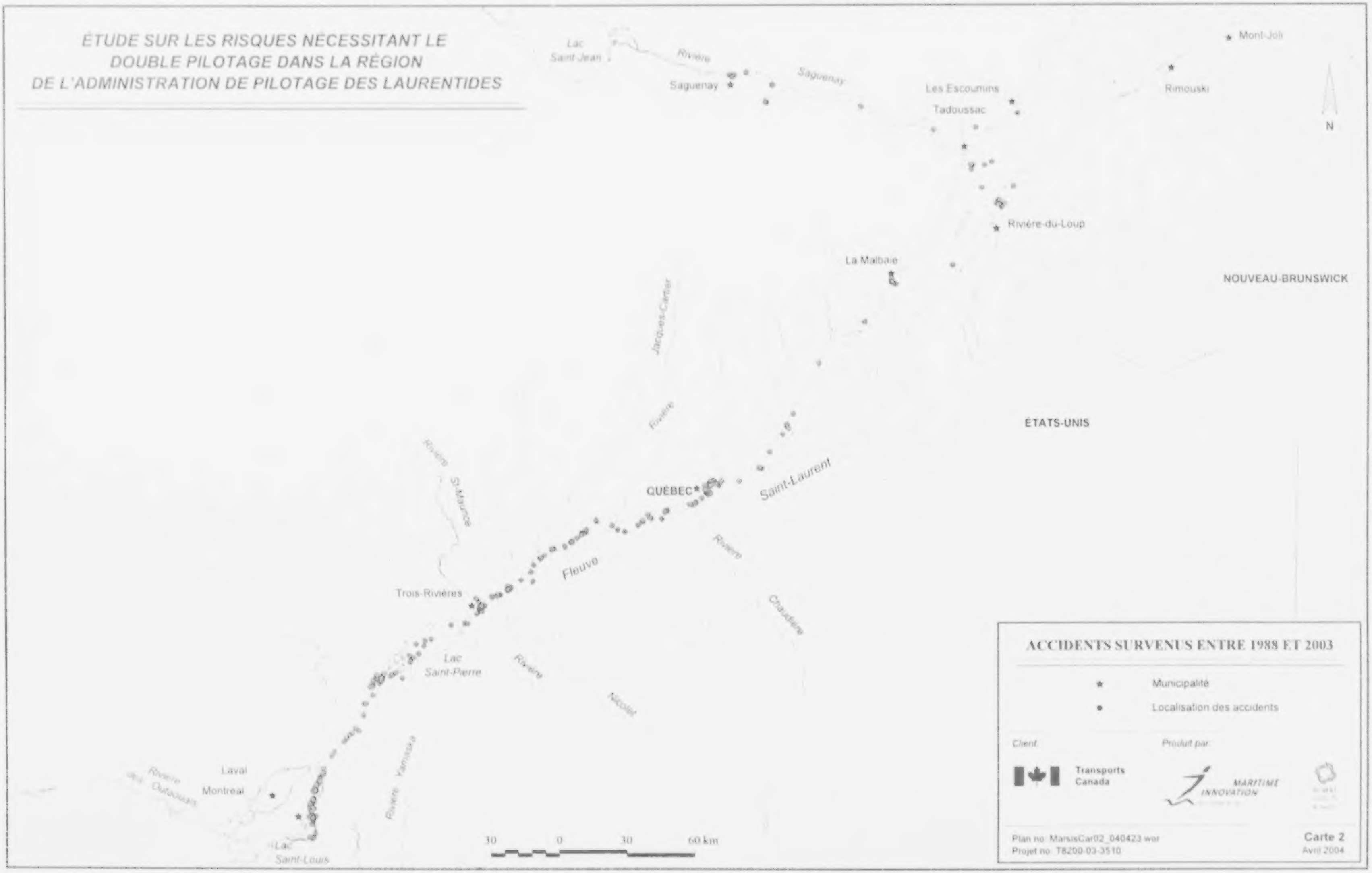
Client
Transports Canada

Produit par
MARITIME INNOVATION

Plan no MarsisCar01_040423.wor
Projet no T8200-03-3510

Carte 1
Avril 2004

# ÉTUDE SUR LES RISQUES NÉCESSITANT LE DOUBLE PILOTAGE DANS LA RÉGION DE L'ADMINISTRATION DE PILOTAGE DES LAURENTIDES

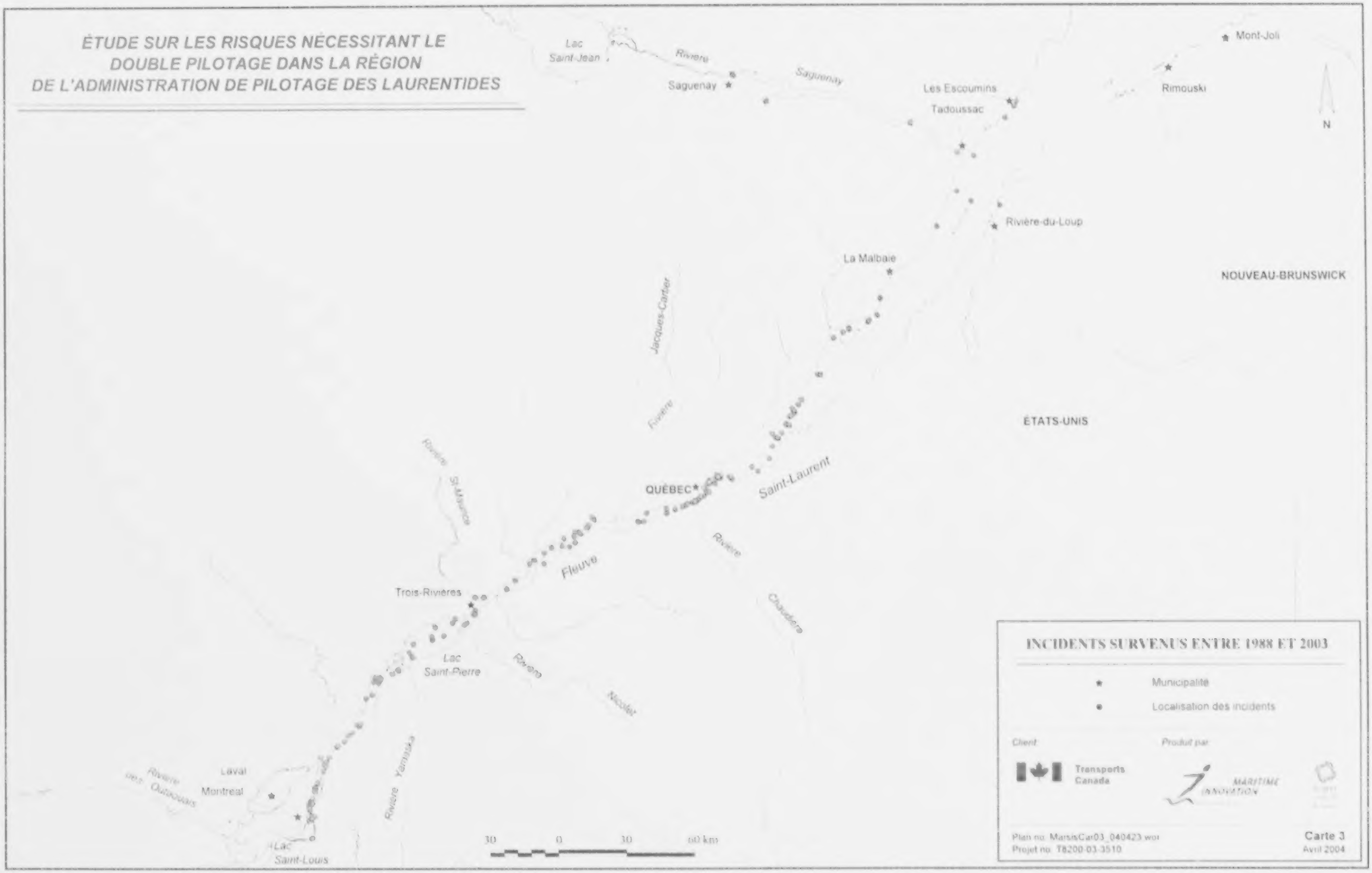


ACCIDENTS SURVENUS ENTRE 1988 ET 2003

Plan no: MarsisCar02_040423.wor
Projet no: T8200-03-3510

Carte 2
Avril 2004

## ÉTUDE SUR LES RISQUES NÉCESSITANT LE DOUBLE PILOTAGE DANS LA RÉGION DE L'ADMINISTRATION DE PILOTAGE DES LAURENTIDES



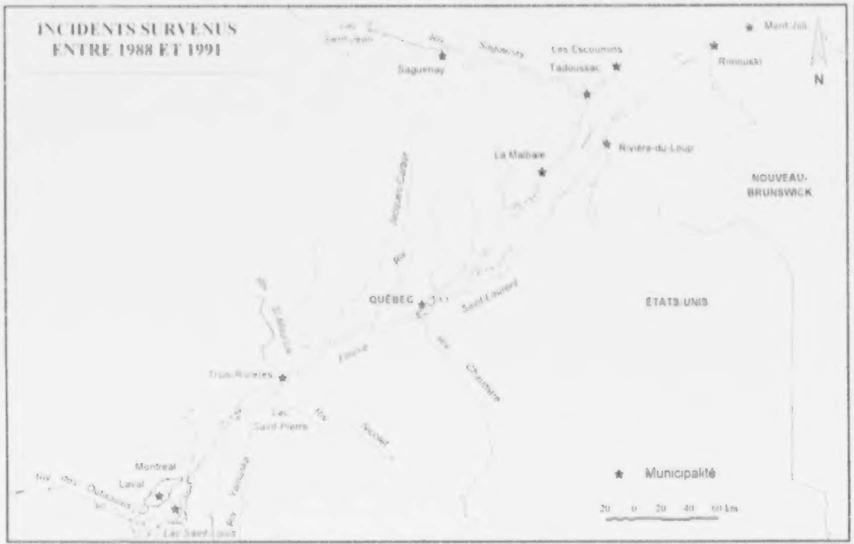
INCIDENTS SURVENUS ENTRE 1988 ET 2003

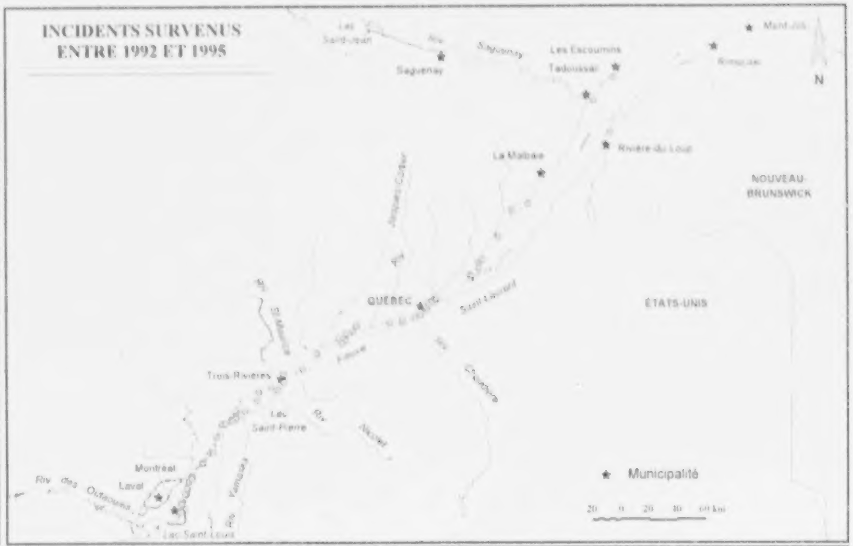
★ Municipalité
● Localisation des incidents

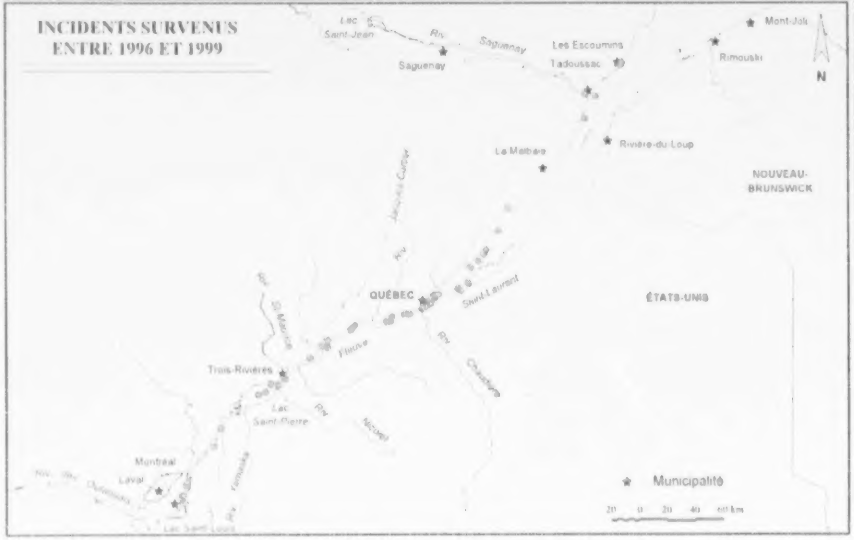
Client: Transports Canada
Produit par: Maritime Innovation

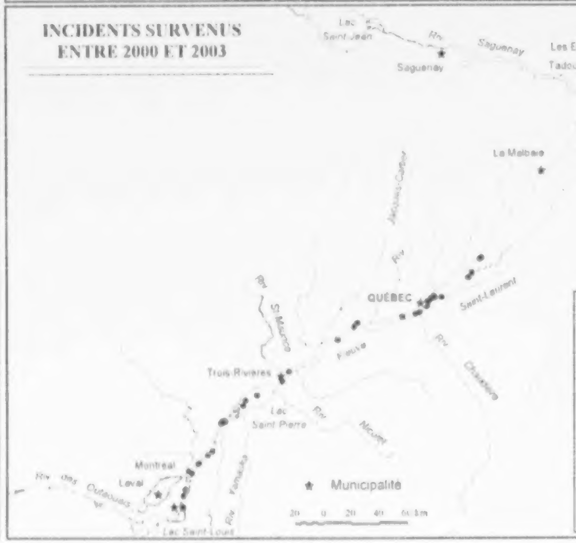
Plan no. MarsisCar03_040423.wor
Projet no. T8200-03-3510

Carte 3
Avril 2004


INCIDENTS SURVENUS
ENTRE 1988 ET 1991


INCIDENTS SURVENUS
ENTRE 1992 ET 1995


INCIDENTS SURVENUS
ENTRE 1996 ET 1999


INCIDENTS SURVENUS
ENTRE 2000 ET 2003

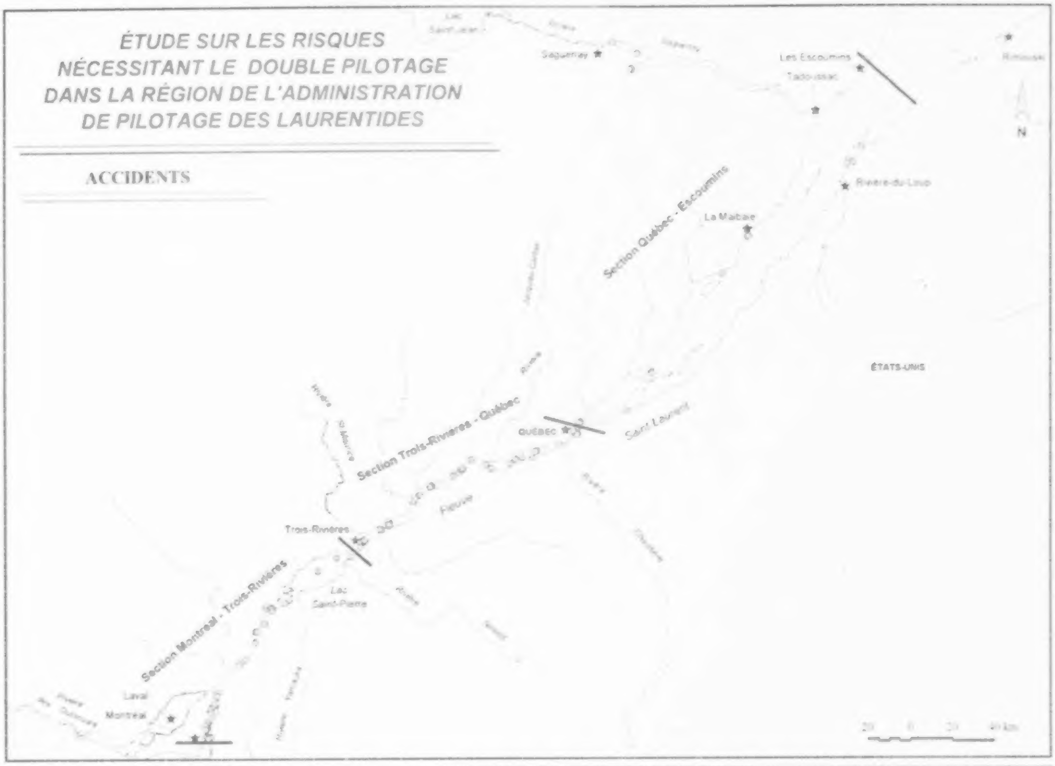
Client:
Transports Canada

Produit par:
MARITIME INNOVATION

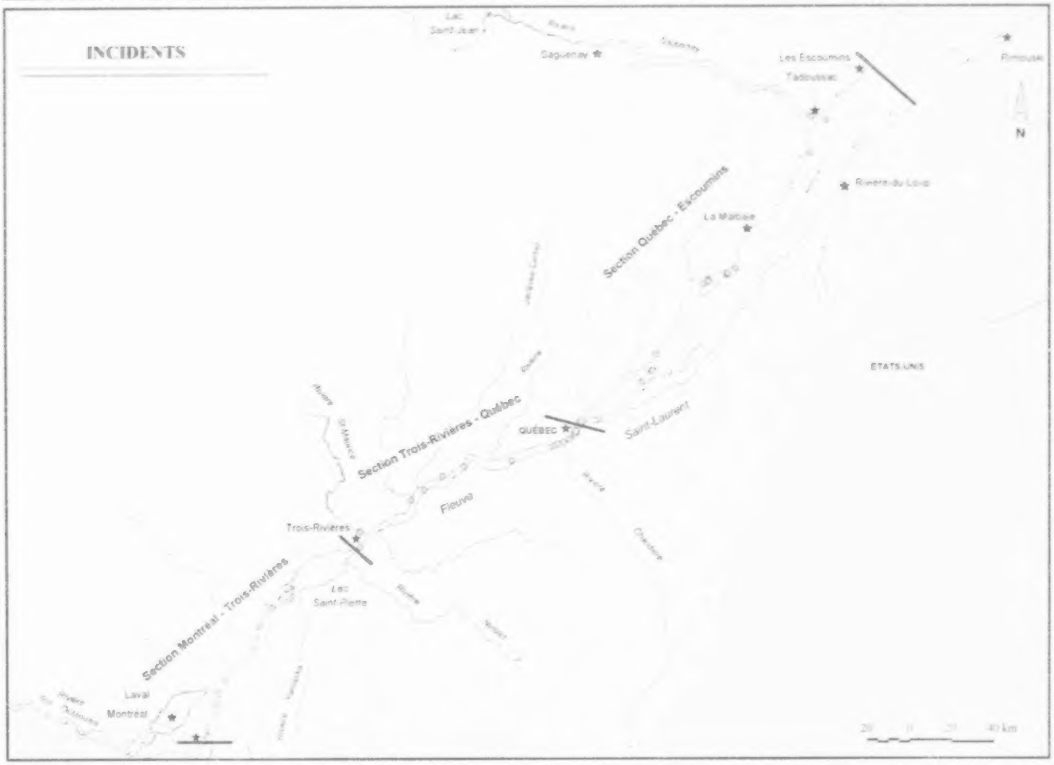
Plan no. MarsisCar03a_040423.wor
Projet no. T8200-03-3510
Avril 2004
Carte 3a

# ÉTUDE SUR LES RISQUES NÉCESSITANT LE DOUBLE PILOTAGE DANS LA RÉGION DE L'ADMINISTRATION DE PILOTAGE DES LAURENTIDES

## ACCIDENTS



## INCIDENTS



★ Municipalité

Limite des secteurs

**Pilotage**

Présence d'un pilote

Inconnu

## ACCIDENTS ET INCIDENTS SURVENUS EN MONTANT

*Client:* Transports Canada

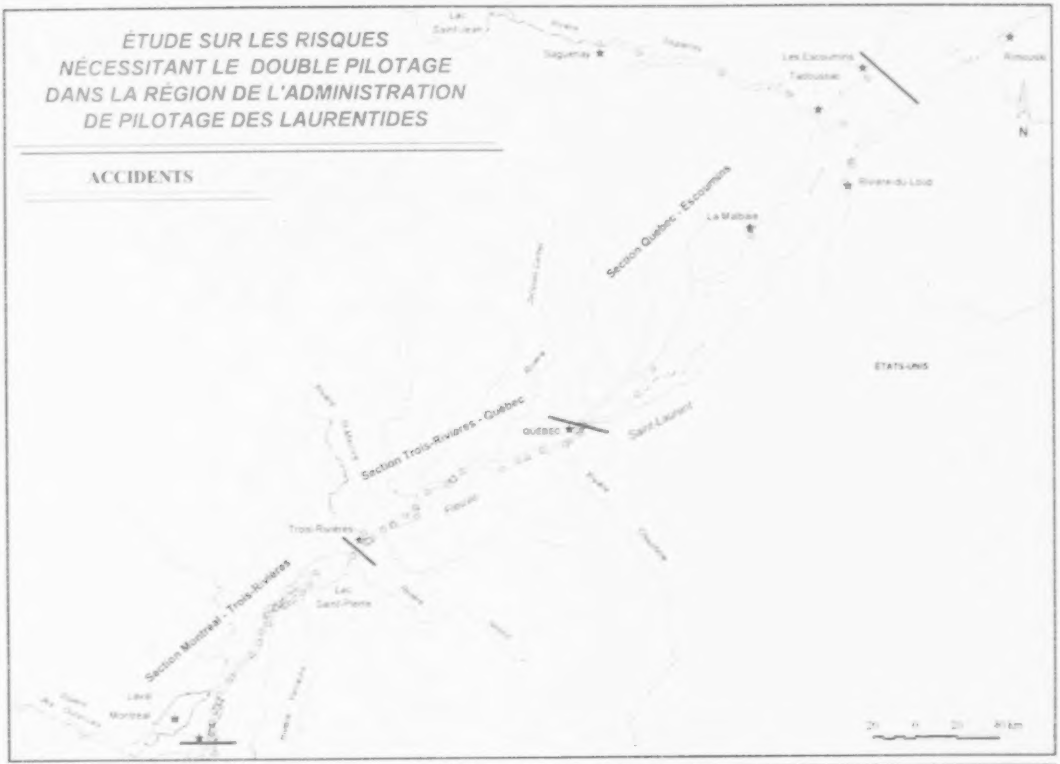
*Produit par:* MARITIME INNOVATION

Plan no: MarsisCar04_040423.wor
Projet no: T8200-03-3510

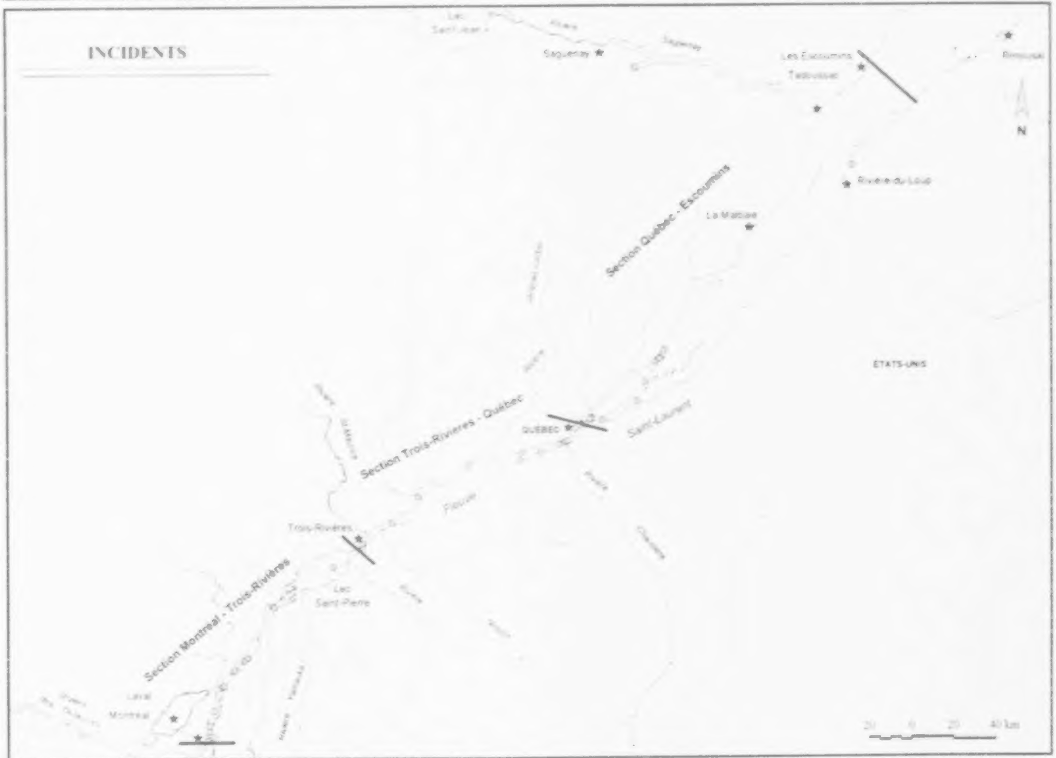
Carte 4
Avril 2004

# ÉTUDE SUR LES RISQUES NÉCESSITANT LE DOUBLE PILOTAGE DANS LA RÉGION DE L'ADMINISTRATION DE PILOTAGE DES LAURENTIDES

## ACCIDENTS



## INCIDENTS



★ Municipalité

Limite des secteurs

**Pilotage**

Présence d'un pilote

Inconnu

## ACCIDENTS ET INCIDENTS SURVENUS EN DESCENDANT

Client

Transports Canada

Produit par

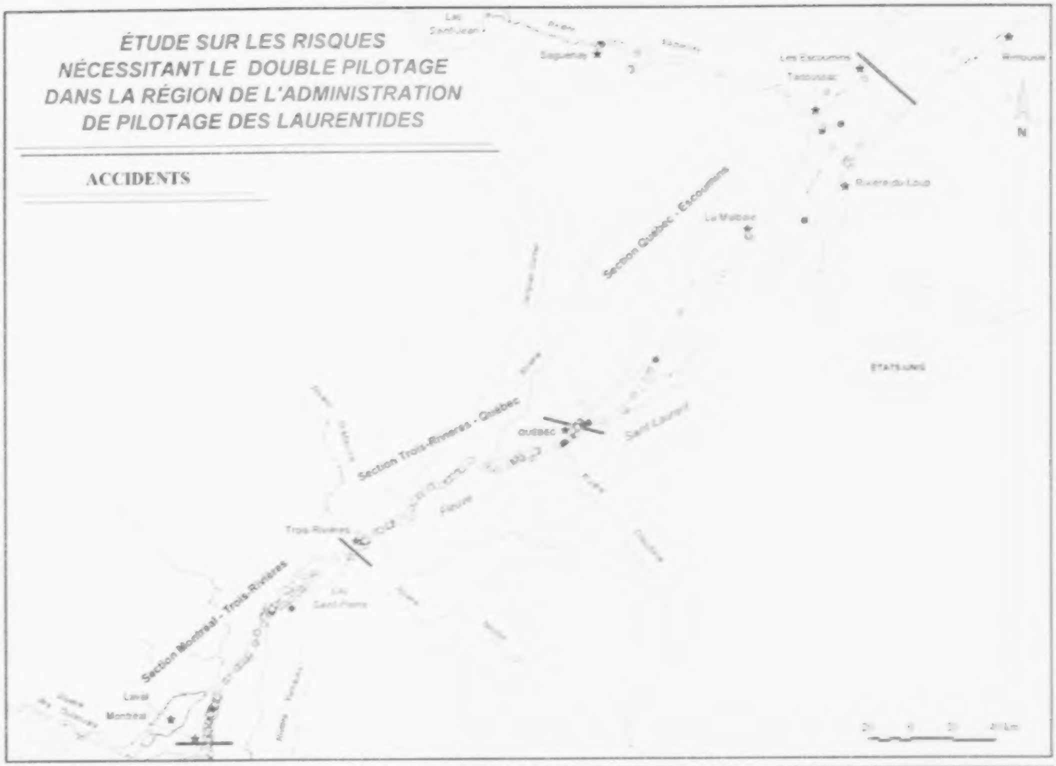
MARITIME INNOVATION

Plan no: MarsisCar05_040423.wor
Projet no: T8200-03-3510

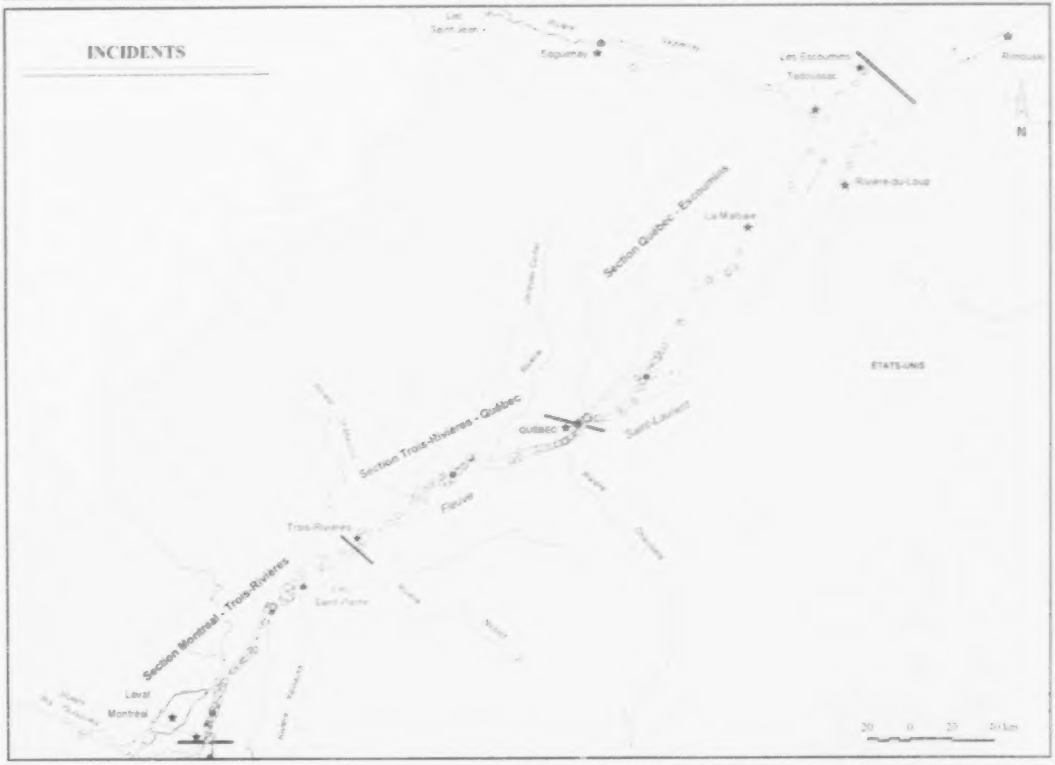
**Carte 5**
Avril 2004

# ÉTUDE SUR LES RISQUES NÉCESSITANT LE DOUBLE PILOTAGE DANS LA RÉGION DE L'ADMINISTRATION DE PILOTAGE DES LAURENTIDES

## ACCIDENTS



## INCIDENTS



★ Municipalité

Limite des secteurs

**Type de navire**

Citerne

Vraquiers

Marchand

● Autres

● Passagers

**TYPE DE NAVIRES IMPLIQUÉS DANS UN ACCIDENT OU UN INCIDENT**

Client:
Transports Canada

Produit par:
MARITIME INNOVATION

Plan no: MarsisCar06_040423.wor
Projet no: T8200-03-3510

Carte 6
Avril 2004

# APPENDIX 5

## Scenarios

# Scenario 1

## Wrong manoeuvre ordered

# Human Error and Possible Consequences in Confined Waters

## Scenario 1

## Wrong manoeuvre ordered

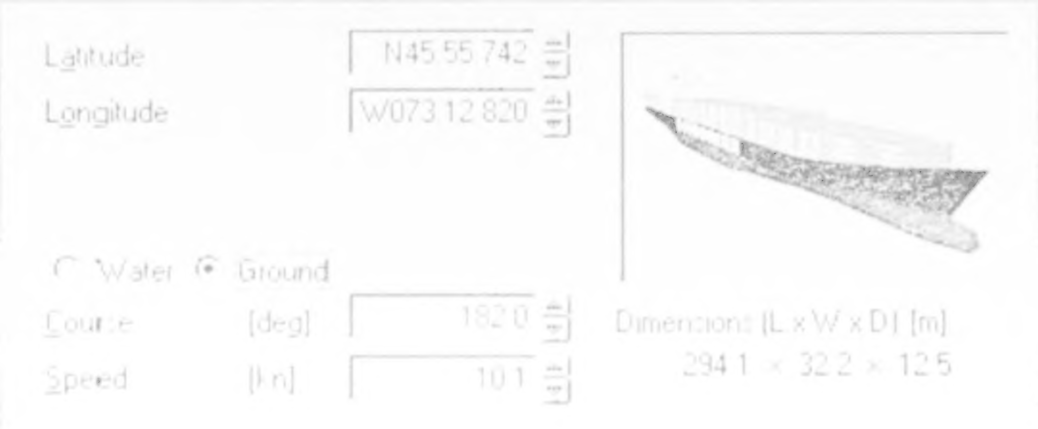
MARITIME INNOVATION

ROBERT
HAMELIN
& associés

## Carrier: Container ship

- 294 m ship
- Beam: 32 m
- Displacement: 70,000 cubic metres
- Max. forward speed: 28 knots
- Max. reverse speed: 8 knots
- Engine: 48,500 kW
- Draft forward: 9 m

Stylized appearance of carrier



Latitude N45 55 742

Longitude W073 12 820

○ Water ● Ground

Course [deg] 182 0

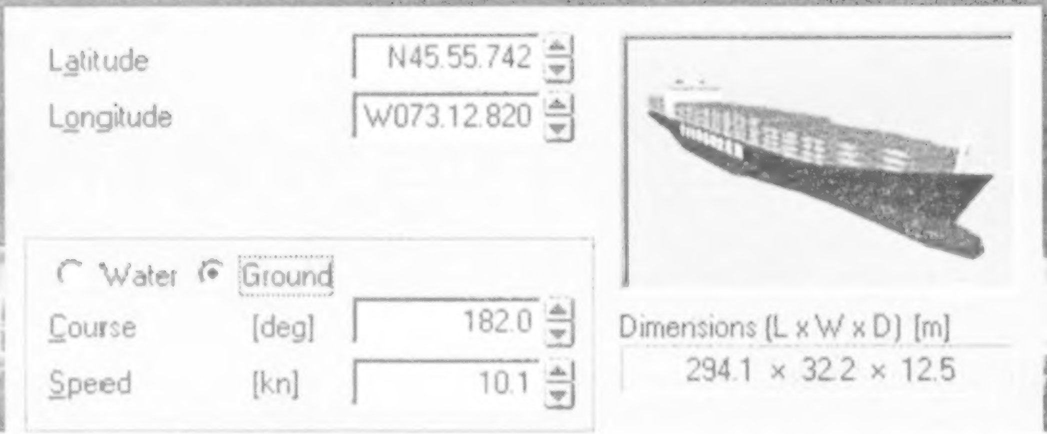
Speed [kn] 10 1

Dimensions [L x W x D] [m]
294 1 × 32 2 × 12 5

## Carrier: Container ship

- 294 m ship
- Beam:  32 m
- Displacement: 70,000 cubic metres
- Max. forward speed: 28 knots
- Max. reverse speed: 8 knots
- Engine: 48,500 kW
- Draft forward: 9 m

Stylized appearance of carrier



Latitude N45.55.742

Longitude W073.12.820

○ Water ● Ground

Course [deg] 182.0

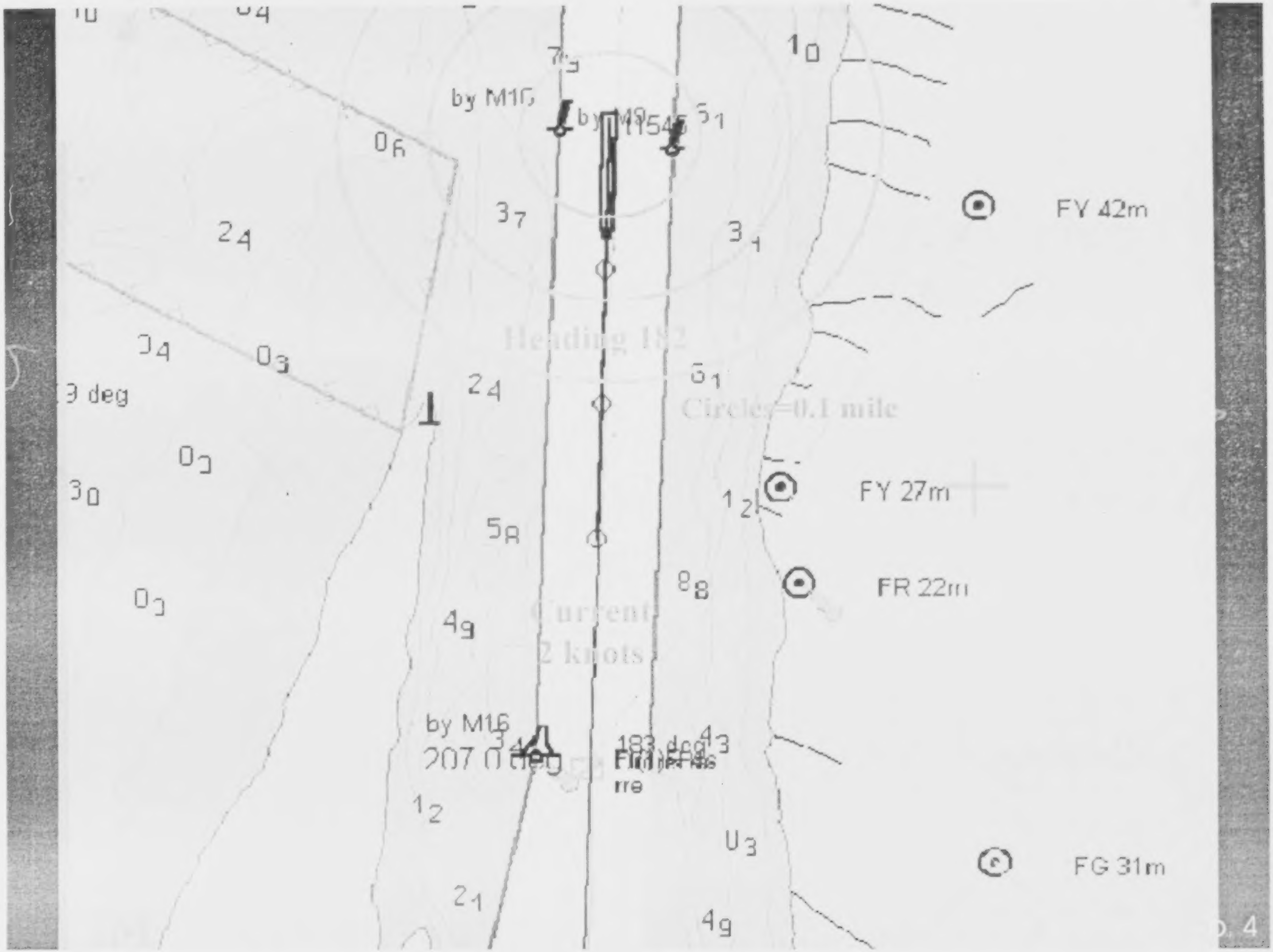
Speed [kn] 10.1

Dimensions (L x W x D) [m]

294.1 × 32.2 × 12.5

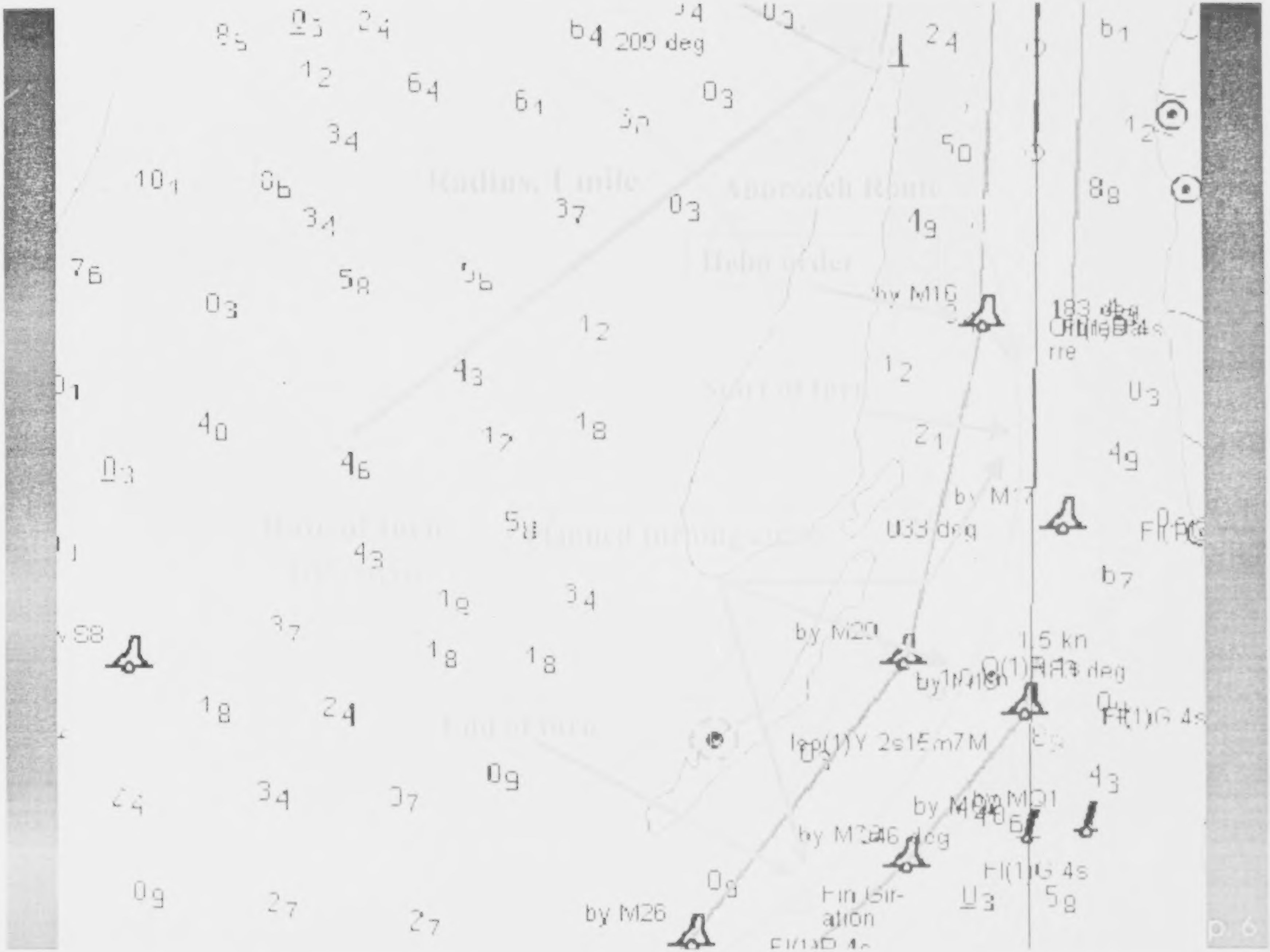
## .Hypothetical situation

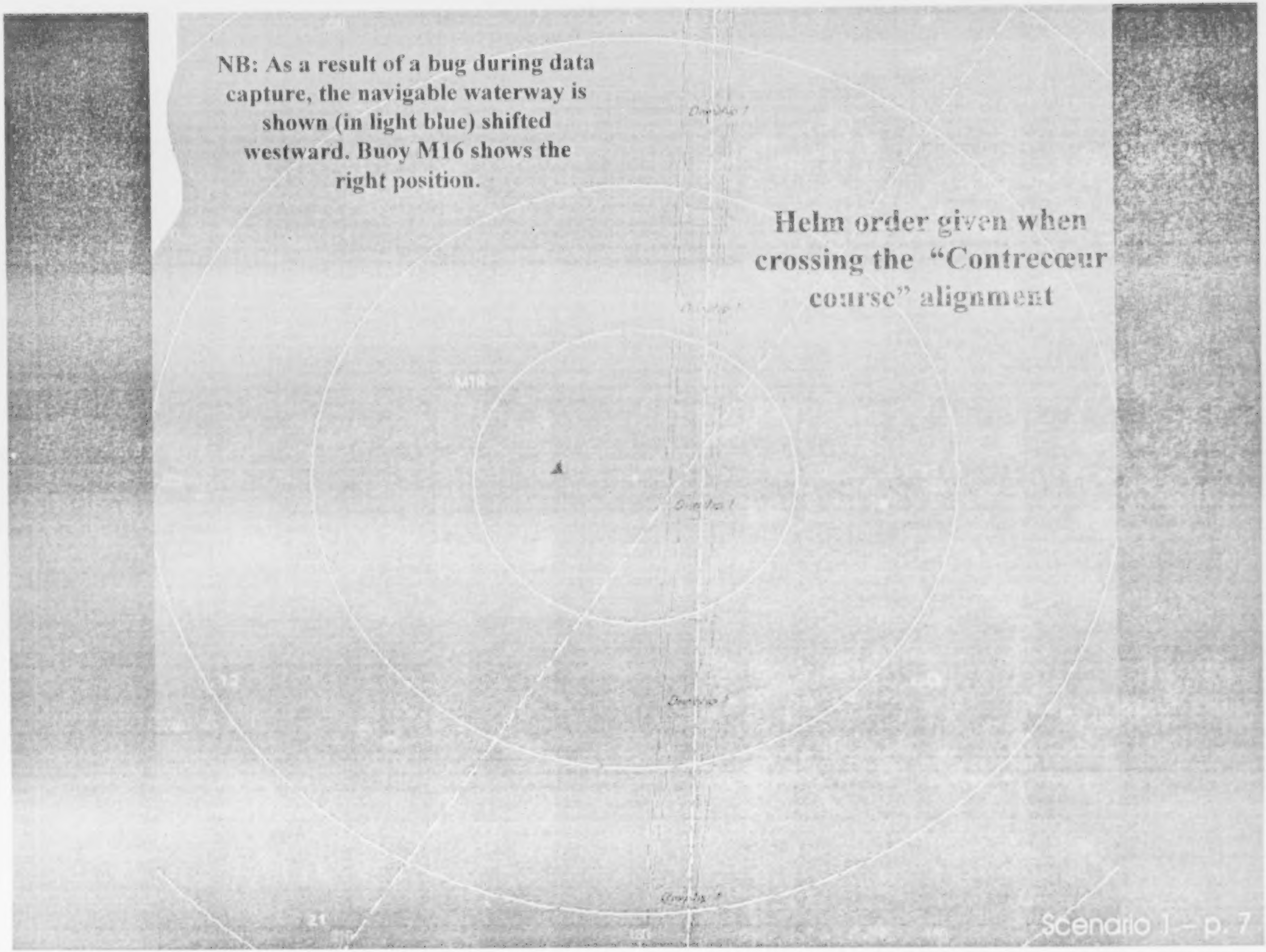
- Ship upbound on "Île-Saint-Ours course"
- Speed over ground: 10 knots
- Heading 182
- No traffic
- Moderate visibility
- Light SW wind


Heading 182
Circle=0.1 mile
Current
2 knots
FY 42m
FY 27m
FR 22m
FG 31m
by M16
by M9
11545
by M16
207.0 deg
183 deg
3 deg

# Sequence of events

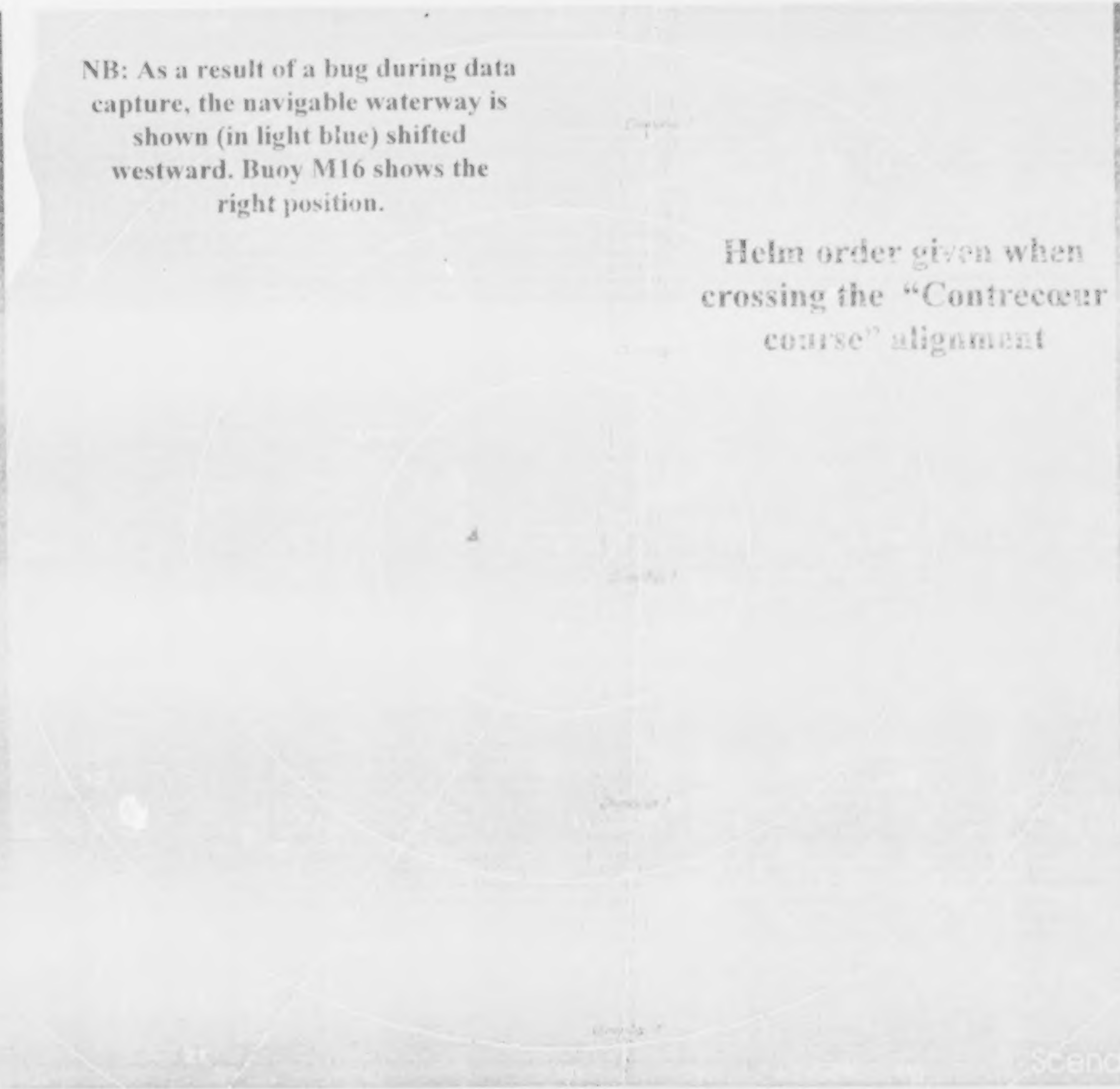
- The ship is upbound at buoy M10, on the "Île Saint-Ours course" alignment, and its speed over ground is 10 knots
- The master has had his officers plan a curved course with radius 1 mile starting from a point midway between buoys M16 and M17 on the alignment and ending midway between buoys M26 and M23, on the "Petite Traverse Contrecœur" alignment
- He has asked the pilot to negotiate the turn with a turning rate of 10° per minute
- The pilot agrees but warns the master that while he knows the method, he has never actually used it
- The master reassures the pilot, saying that he uses the method regularly
- The pilot expresses doubts in view of the current
- The master tells him that when the ratio Speed over ground : Radius : Rate-of-turn is kept at Sg x 360 : 2 x pi x R x 60, there is no problem (*we'll come back to this*)
- The next slide shows the master's plan as presented to the pilot


Radius, 1 mile
Approach Route
Helm order
Start of turn
Planned turning circle
End of turn
b4 209 deg
183 deg
by M16
by M17
U33 deg
by M20
1.5 kn
Q(1)R 3s
by M26
by M01
Iso(1)Y 2s15m7M
Fl(1)G 4s
Fl(1)G 4s
Fl(1)R 4s
Fin Gir-
ation
p. 6



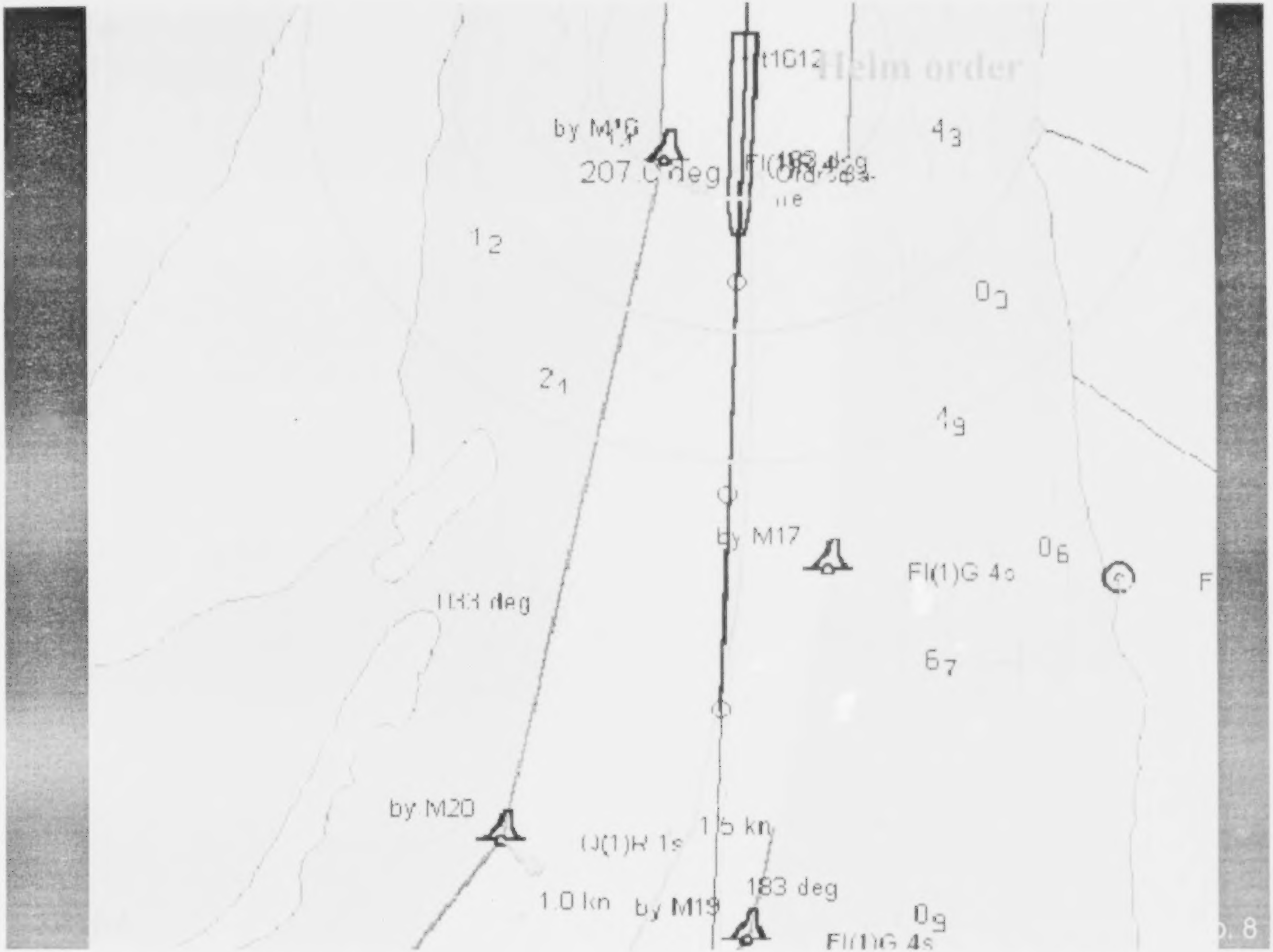
NB: As a result of a bug during data capture, the navigable waterway is shown (in light blue) shifted westward. Buoy M16 shows the right position.

Helm order given when crossing the "Contrecœur course" alignment



NB: As a result of a bug during data capture, the navigable waterway is shown (in light blue) shifted westward. Buoy M16 shows the right position.

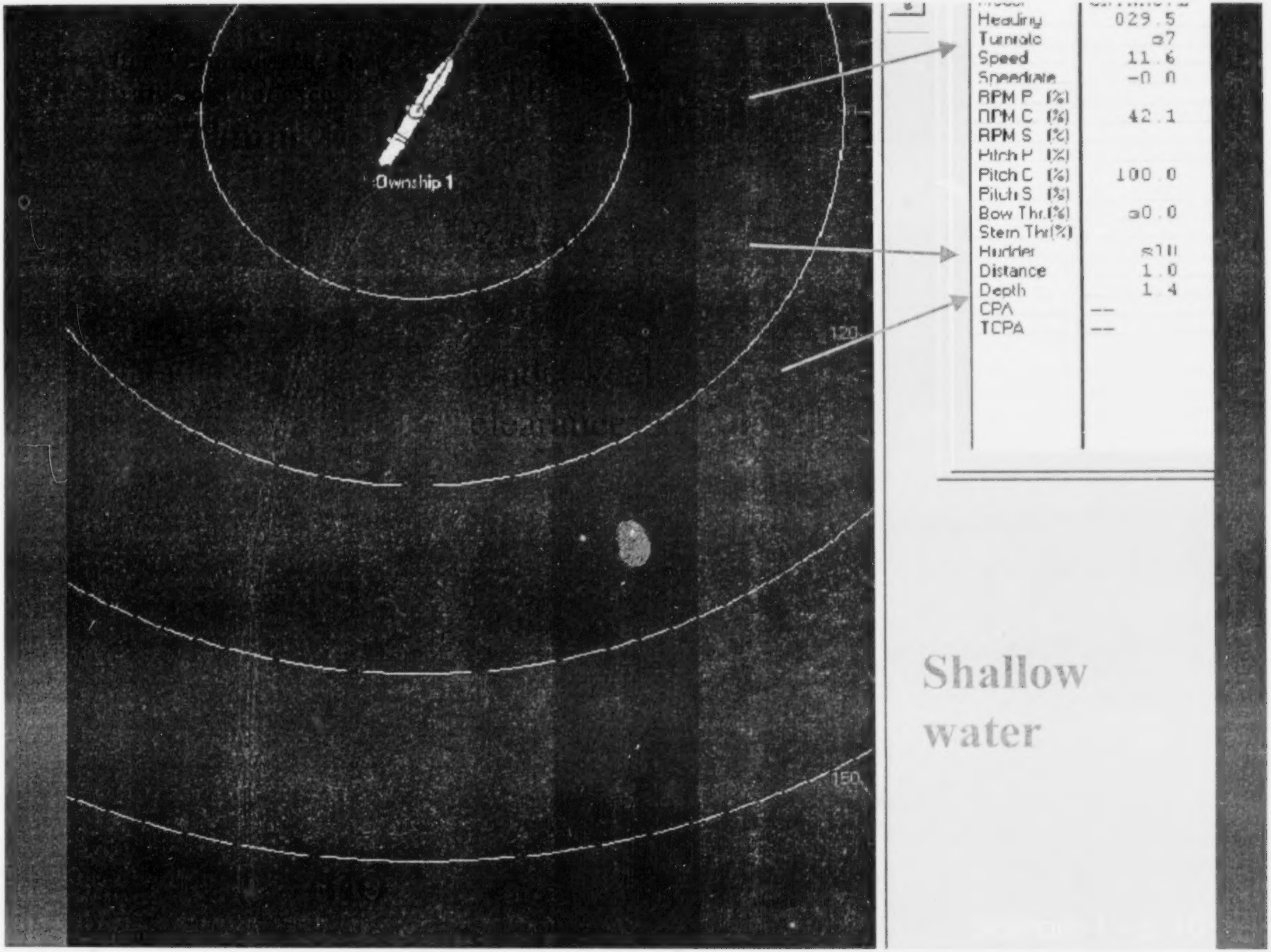
Helm order given when crossing the "Contrecœur course" aligament


Helm order
t1612
by M19
207.0 deg
Fl(1)G 4s
183 deg
4₃
1₂
0₃
2₁
4₉
by M17
Fl(1)G 4s
0₆
F
183 deg
6₇
by M20
Q(1)R 1s
1.5 kn
1.0 kn
by M19
183 deg
0₉
Fl(1)G 4s
0.8

- The helmsman positions the wheel at 10° starboard and awaits the planned rate of 10°/min

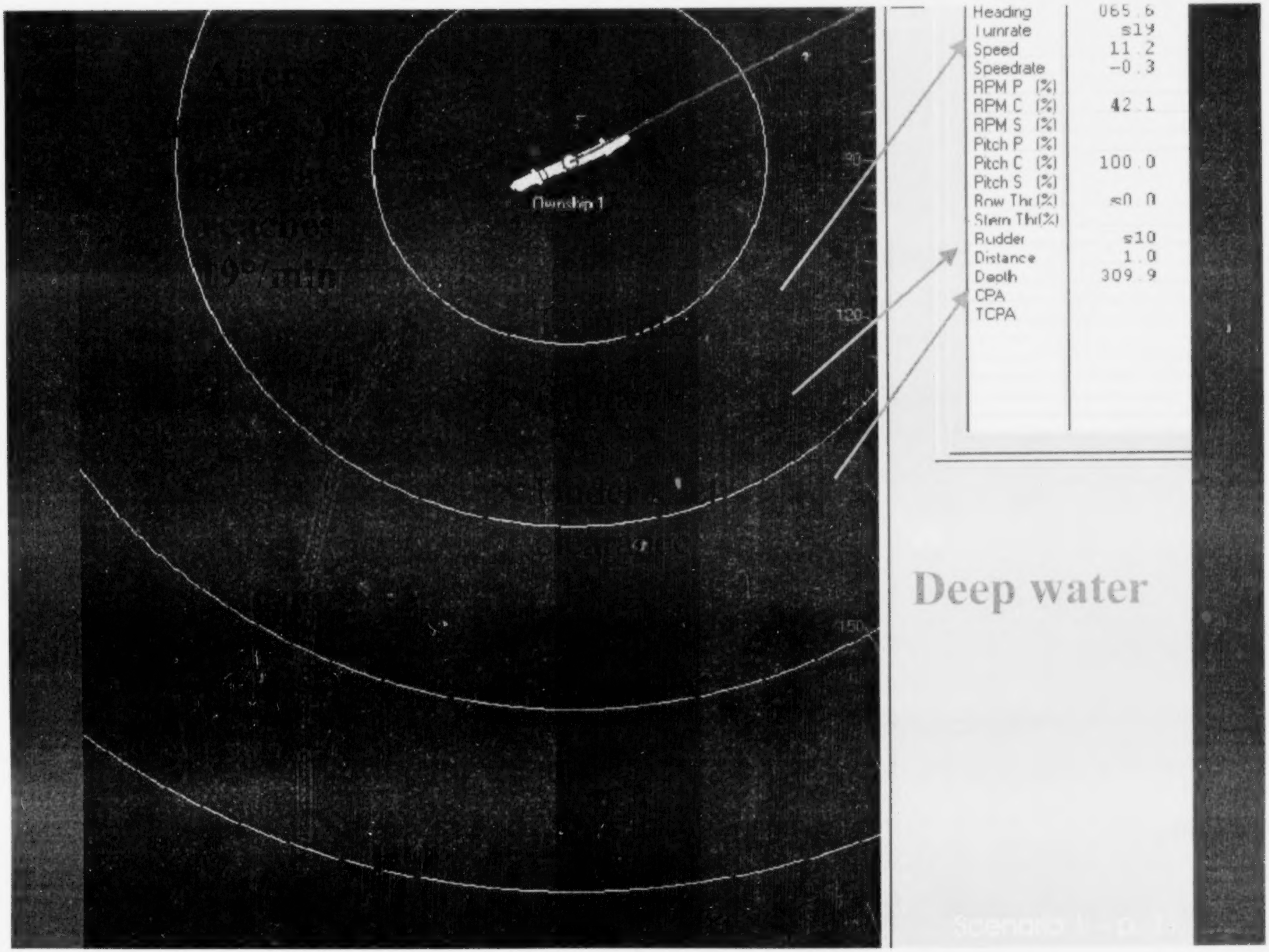
- According to simulator tests in deep waters, a turn rate of 10°/min is reached after 1½ ship lengths and is maintained by holding the wheel between 5° and 6° starboard

- The under-keel clearance is about 1.2 metres (estimated squat taken into consideration)



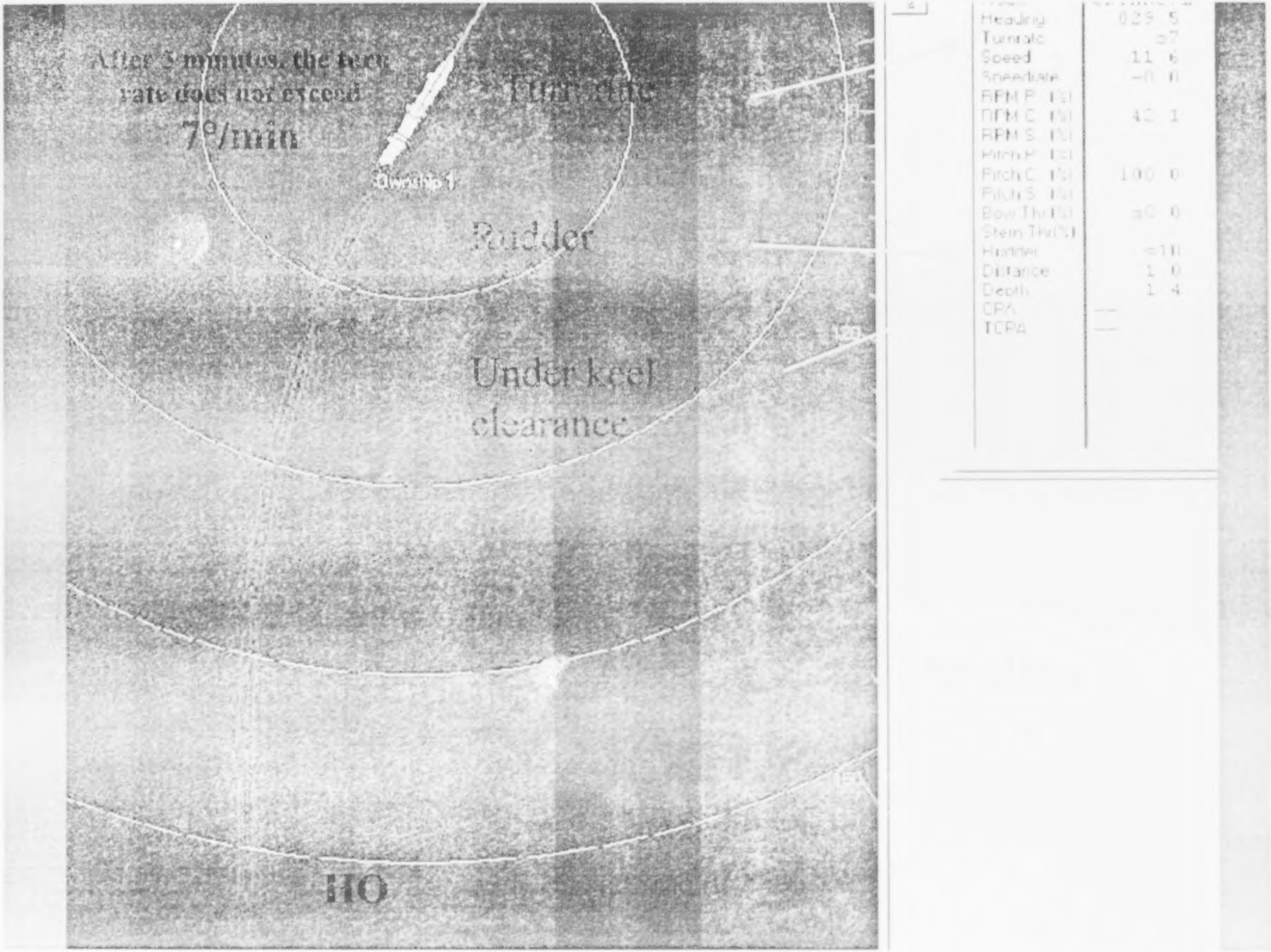
| | |
|---|---|
| Heading | 029.5 |
| Turnrate | a7 |
| Speed | 11.6 |
| Speedrate | -0.0 |
| RPM P (%) | |
| RPM C (%) | 42.1 |
| RPM S (%) | |
| Pitch P (%) | |
| Pitch C (%) | 100.0 |
| Pitch S (%) | |
| Bow Thr.(%) | a0.0 |
| Stern Thr(%) | |
| Rudder | ≈10 |
| Distance | 1.0 |
| Depth | 1.4 |
| CPA | -- |
| TCPA | -- |

Shallow
water



| | |
|---|---|
| Heading | 065.6 |
| Turnrate | s19 |
| Speed | 11.2 |
| Speedrate | -0.3 |
| RPM P (%) | |
| RPM C (%) | 42.1 |
| RPM S (%) | |
| Pitch P (%) | |
| Pitch C (%) | 100.0 |
| Pitch S (%) | |
| Bow Thr (%) | s0.0 |
| Stern Thr(%) | |
| Rudder | s10 |
| Distance | 1.0 |
| Depth | 309.9 |
| CPA | |
| TCPA | |

Deep water



After 3 minutes, the turn rate does not exceed

7°/min

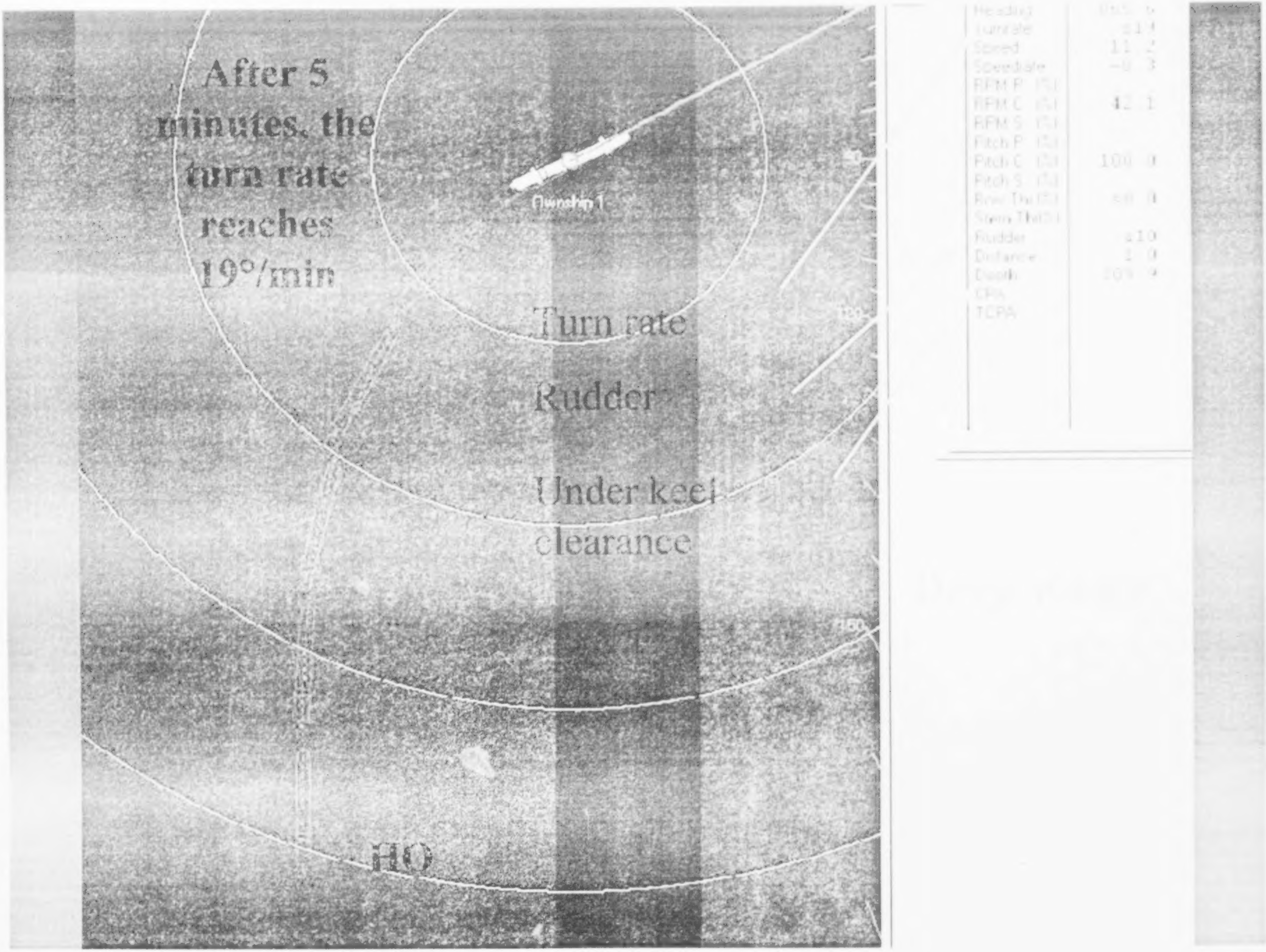
Turn rate

Rudder

Under keel clearance

HO

| | |
|---|---|
| Heading | 029.5 |
| Turnrate | =7 |
| Speed | 11.6 |
| Speedrate | −0.0 |
| RPM P (%) | |
| RPM C (%) | 42.1 |
| RPM S (%) | |
| Pitch P (%) | |
| Pitch C (%) | 100.0 |
| Pitch S (%) | |
| Bow Thr(%) | =0.0 |
| Stern Thr(%) | |
| Rudder | <10 |
| Distance | 1.0 |
| Depth | 1.4 |
| CPA | --- |
| TCPA | --- |



After 5 minutes, the turn rate reaches 19°/min

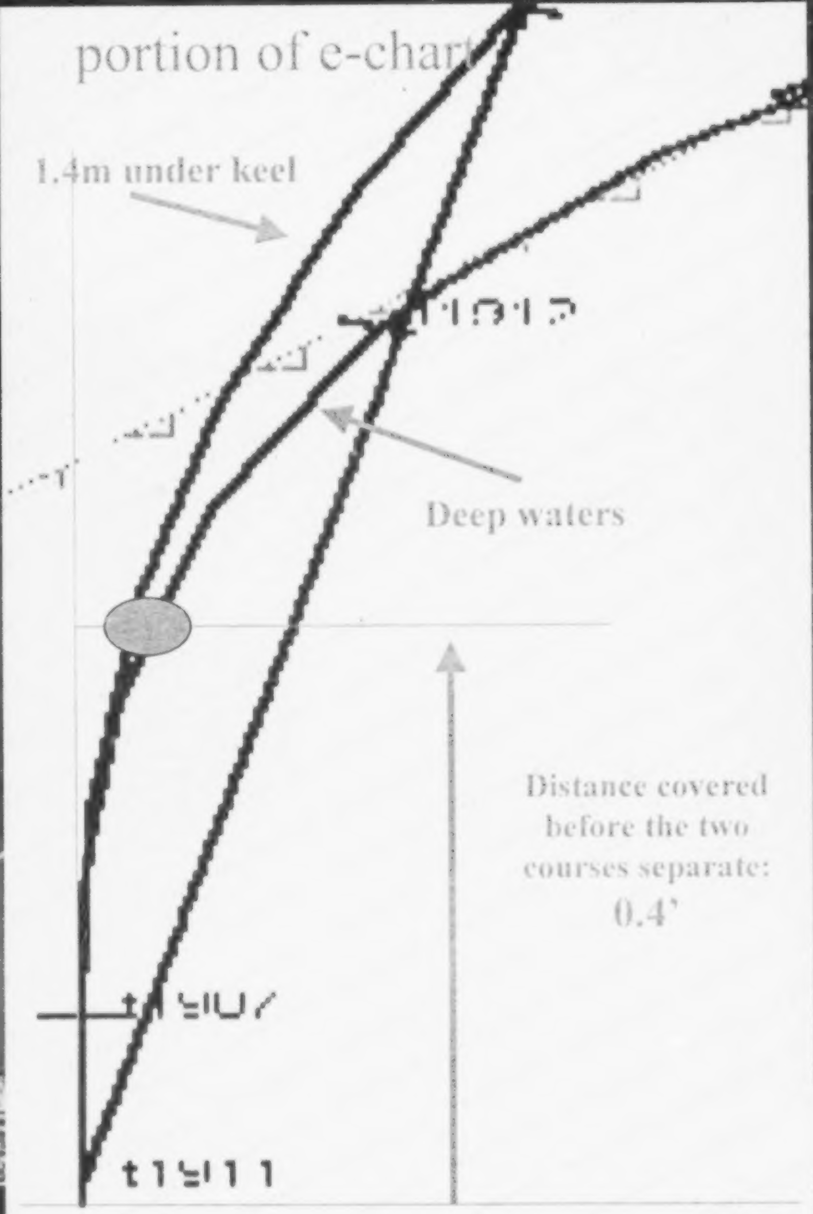
Turn rate

Rudder

Under keel clearance

| | |
|---|---|
| Heading | [illegible] |
| Turnrate | s19 |
| Speed | 11.2 |
| Speedrate | −0.3 |
| RPM P (%) | |
| RPM C (%) | 42.1 |
| RPM S (%) | |
| Pitch P (%) | |
| Pitch C (%) | 100.0 |
| Pitch S (%) | |
| Bow Thr(%) | s0.0 |
| Stern Thr(%) | |
| Rudder | s10 |
| Distance | 1.0 |
| Depth | [illegible] |
| CPA | |
| TCPA | |

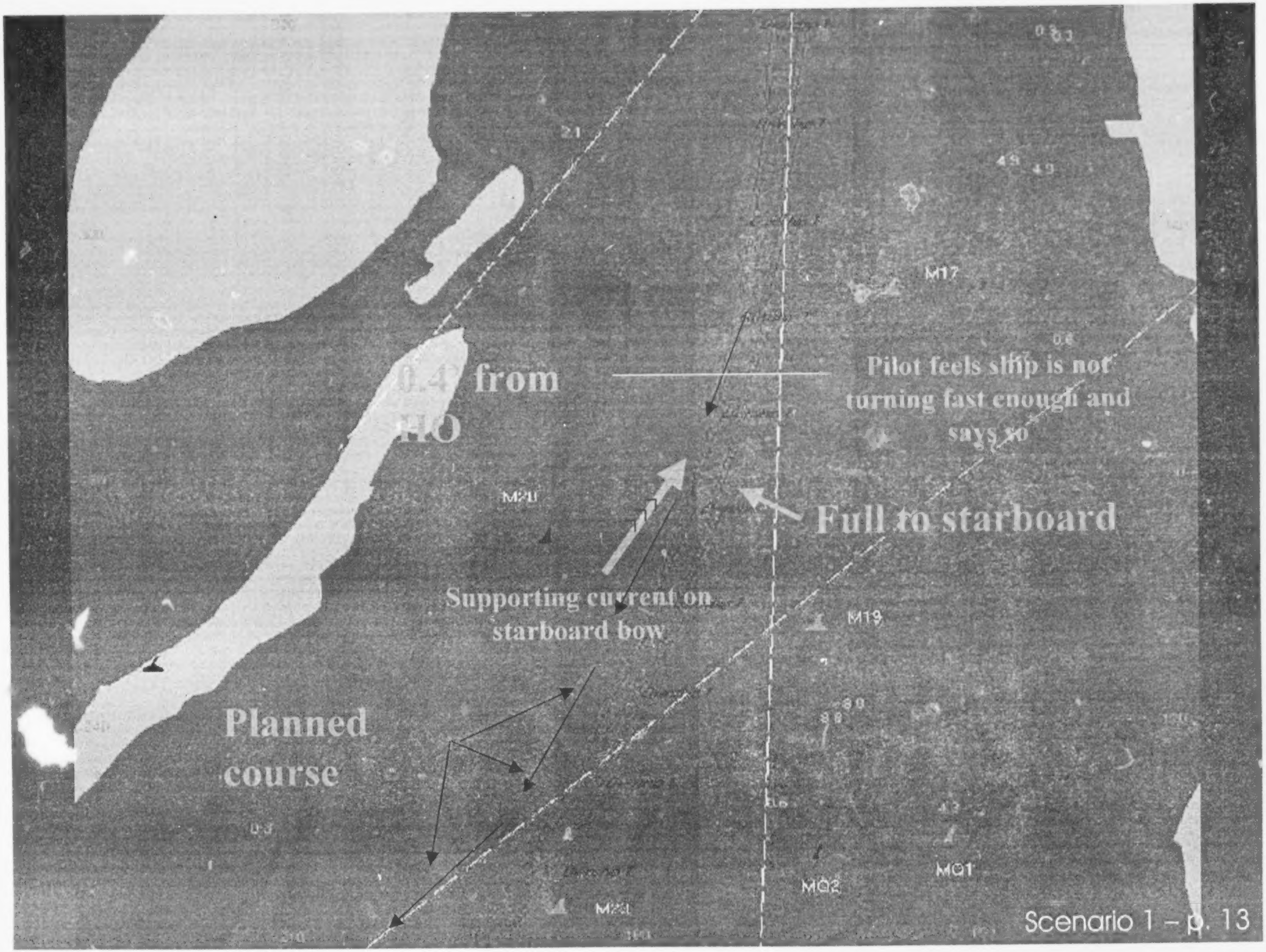
# portion of e-chart



1.4m under keel

Deep waters

Distance covered
before the two
courses separate:
0.4'



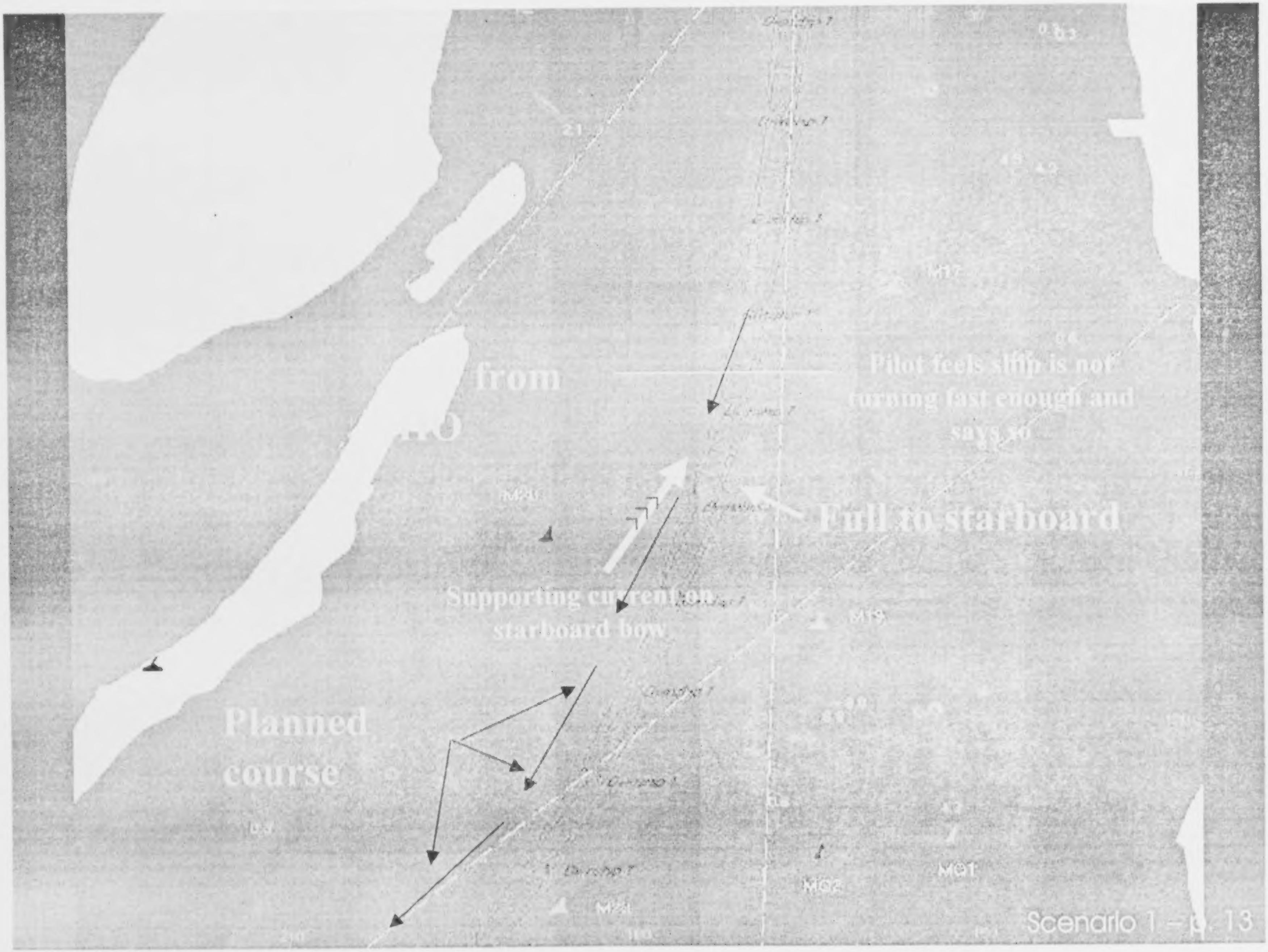
0.4 from HO

Pilot feels ship is not turning fast enough and says so

Full to starboard

Supporting current on starboard bow

Planned course



Planned course

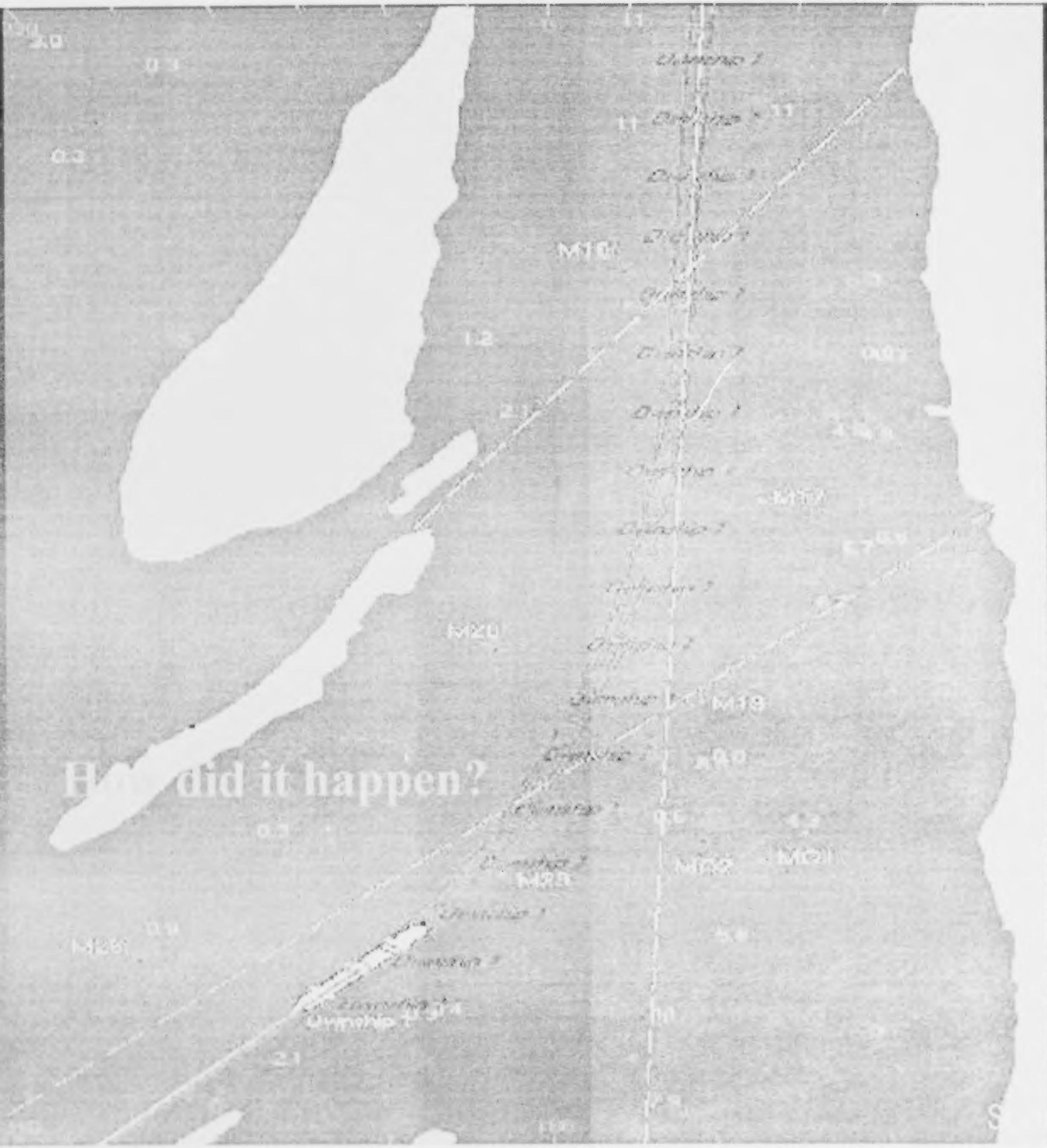
from

Supporting current on starboard bow

Full to starboard

Pilot feels ship is not turning fast enough and says so

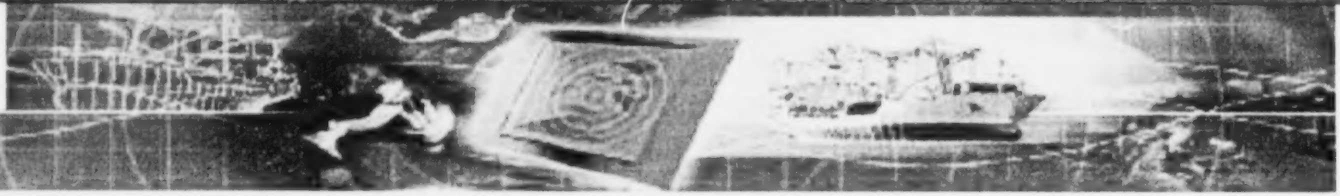
# How did it happen?



- There are 4 main actors on the bridge: master, pilot, officer of the watch, helmsman
- The master has imposed a method known only to himself for negotiating a critical stretch of water. As a result there may be uncertainty as to WHO is in the driver's seat
- The master has not considered the under keel clearance, which calls for more rudder to achieve the desired turn rate. He has also not considered the current on the starboard bow, which will combine with the shallow water effect to slow the turn
- He took a little time to react to the pilot's warning (tunnel vision)
- The pilot should have given a better explanation of the effect of the current at that location, especially on a large vessel
- The watch officer, even if tracking progress on the electronic chart, could not have foreseen that the ship would not follow the planned course before the pilot pointed it out, because the ship had been following that course for at least 0.35'
- The helmsman set the wheel at 10° starboard as usual. He did not foresee that the turn rate would increase very slowly

What mitigation measures can be considered?

- Having a second pilot is one possible measure:
  - The pilots relieve each other every hour, but at critical locations the second pilot pays close attention to what the first pilot and the helmsman are doing
  - A second pilot could have spotted the error and corrective action could have been taken in time
- When the vessel has a big crew, good resource management is another possible mitigation measure: have an extra officer on watch on the bridge whose sole task is to monitor manoeuvres
- His sole task would be to ensure that the manoeuvres are appropriate. But would this second officer have the local knowledge necessary to react in time?
- Are there enough officers for this sort of work? Are the officers sufficiently rested?



## This leads to the following question:

- Could an ECDIS take the place of a second person?
- An ECDIS is a system that displays electronic navigation charts in S-57 format on a screen of regulation size
- Using an ECDIS instead of paper charts, and in compliance with all IMO operating standards, calls for ongoing monitoring by a qualified person when in confined waters or pilotage waters

# Scenario 2

## Error by helmsman

# Human error and possible consequences in confined waters

## Scenario 2

## Error by helmsman

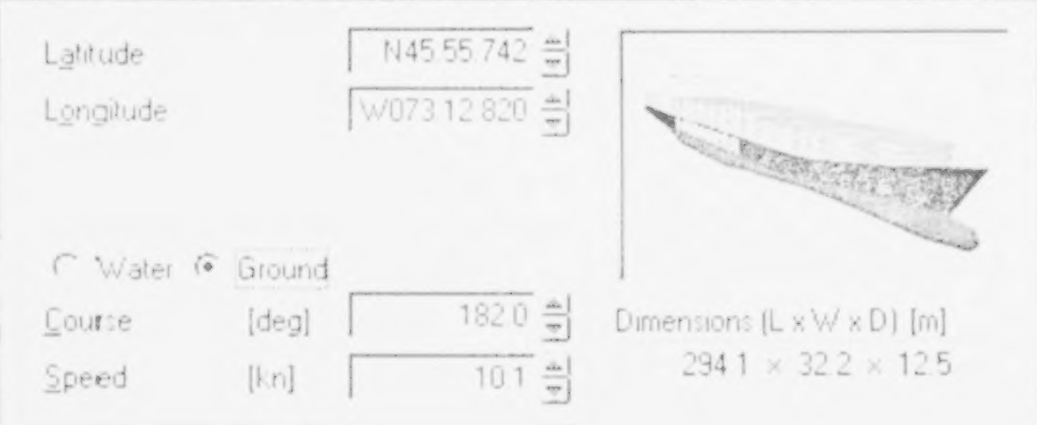
MARITIME INNOVATION

ROBERT HAMELIN & associés

# Carrier: bulker

- 215 m ship
- Beam:  32 m
- Displacement: 60,000 cubic metres
- Max. forward speed: 16 knots
- Max. reverse speed: 6 knots
- Draft aft: 11.5 m
- Engine: 9200 kW

Stylized appearance of carrier

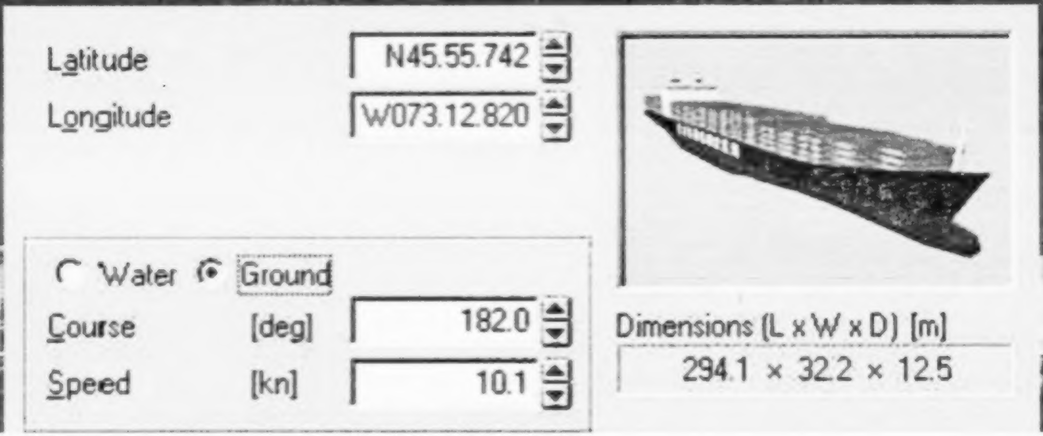


Latitude N45 55.742
Longitude W073 12.820
○ Water ● Ground
Course [deg] 182.0
Speed [kn] 10.1
Dimensions (L x W x D) [m]
294.1 × 32.2 × 12.5

# Carrier: bulker

- 215 m ship
- Beam:  32 m
- Displacement: 60,000 cubic metres
- Max. forward speed: 16 knots
- Max. reverse speed: 6 knots
- Draft aft: 11.5 m
- Engine: 9200 kW

Stylized appearance of carrier



Latitude N45.55.742

Longitude W073.12.820

○ Water ● Ground

Course [deg] 182.0

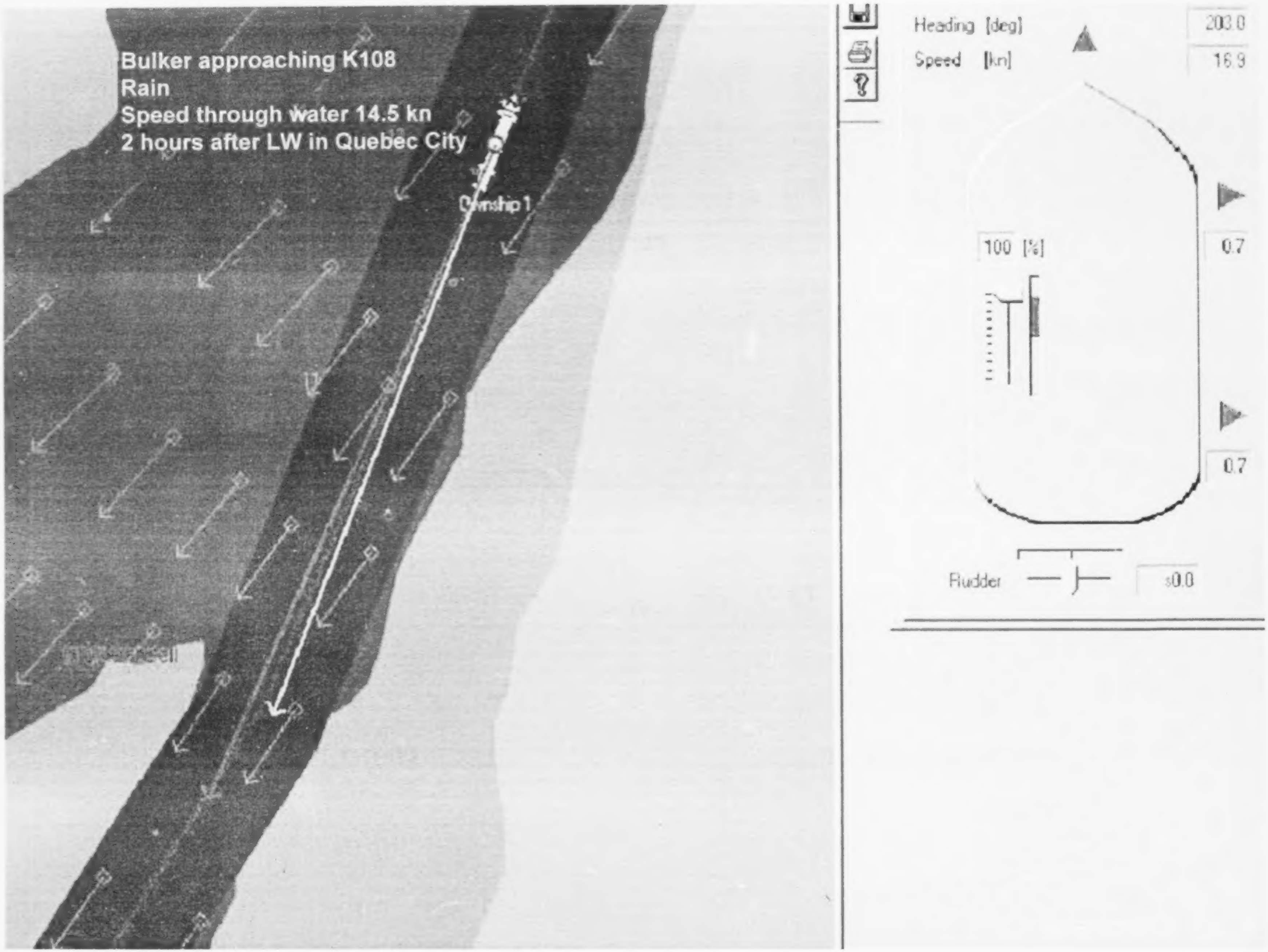
Speed [kn] 10.1

Dimensions (L x W x D) [m]

294.1 × 32.2 × 12.5

## Hypothetical situation

- Ship upbound ¾ of a mile from K108
- Speed through water 14.5 knots
- Visibility moderate to reduced
- Tide: two hours after low tide in Quebec City (i.e., rising tide)
- No ships downbound



Bulker approaching K108
Rain
Speed through water 14.5 kn
2 hours after LW in Quebec City

Heading [deg] 203.0
Speed [kn] 16.9

Rudder s0.0

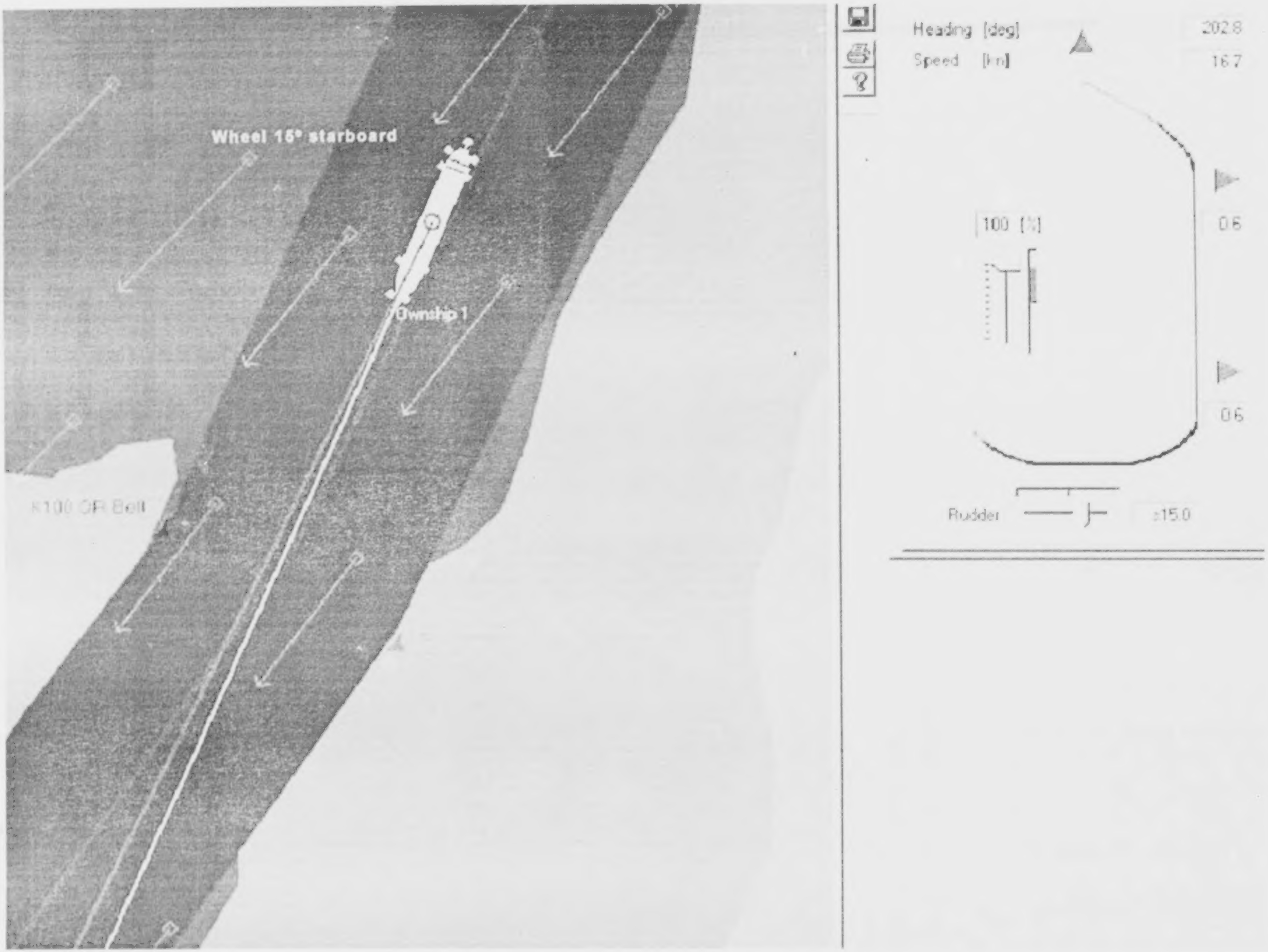
## Sequence of events

- Vessel approaches K108
- 0.2’ from the course alteration point, pilot orders change from 202 to 211

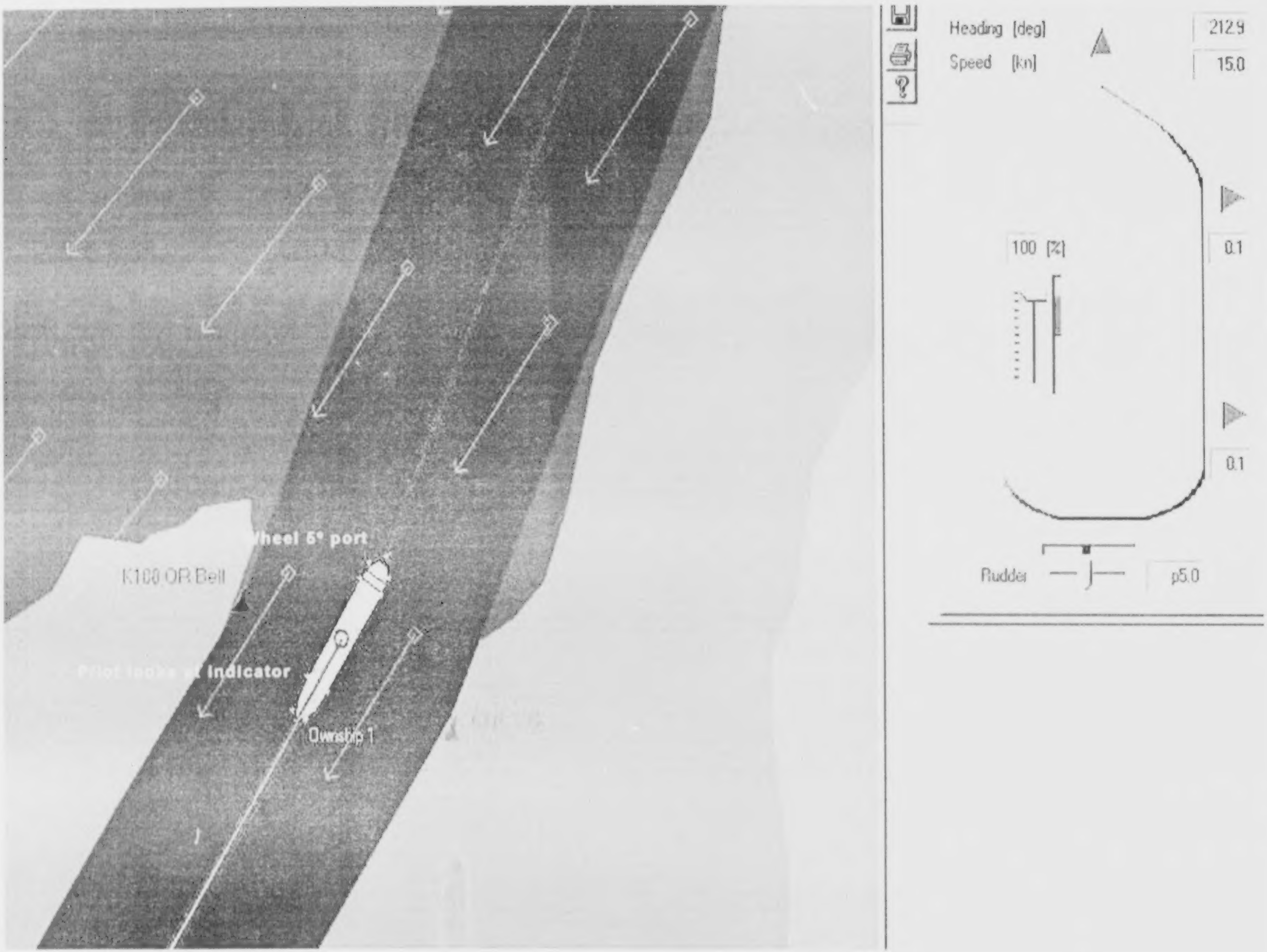
  (course made good over ground: 204° and 213½°)
- Helmsman turns the wheel to starboard 15° to comply with order; pilot verifies with a glance, as does officer of the watch
- OOW takes a bearing and two radar ranges, goes to the chart table to plot the position as the course is changing, and makes his entries in the log (**as required**)

MARITIME INNOVATION

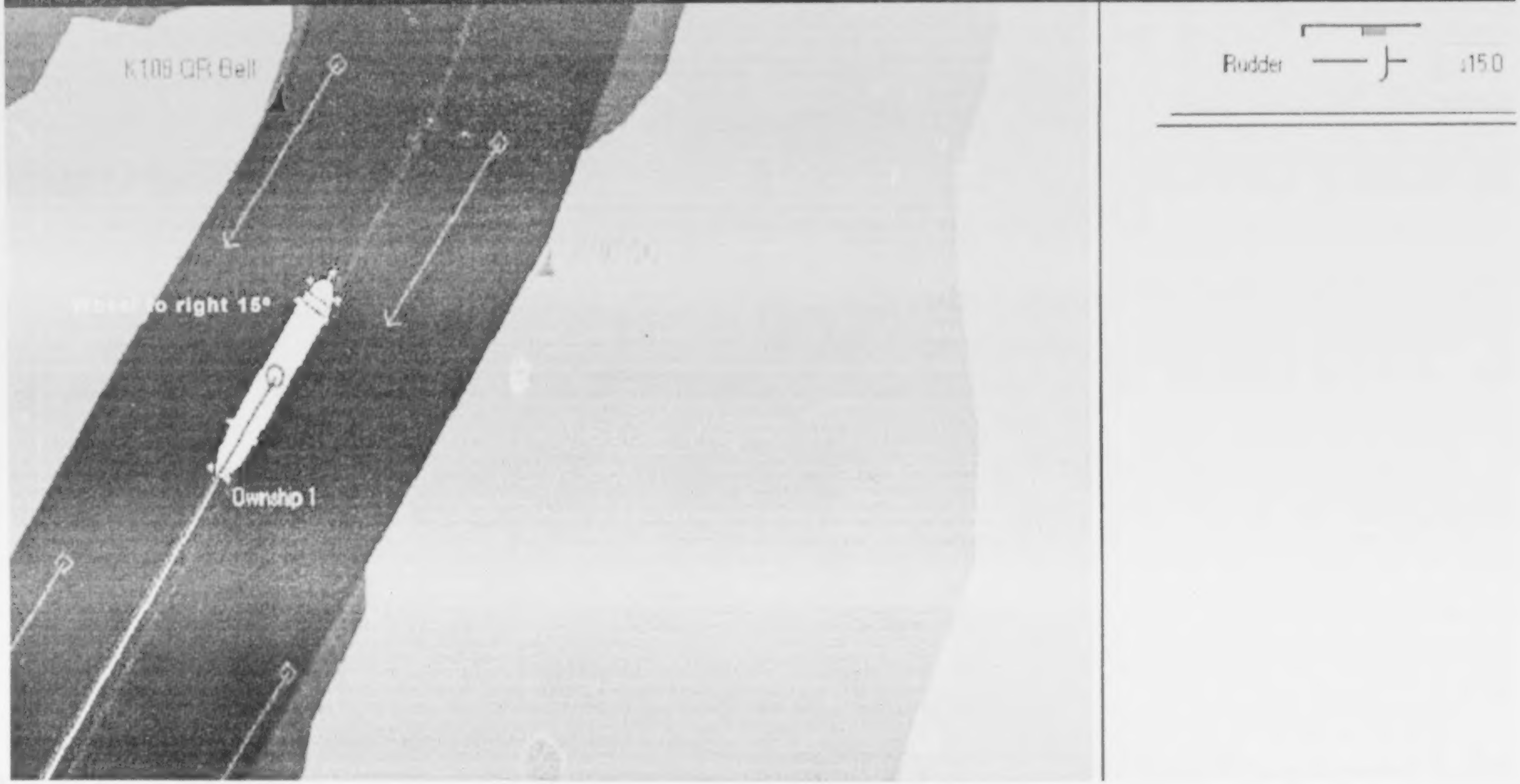
ROBERT HAMELIN & associés

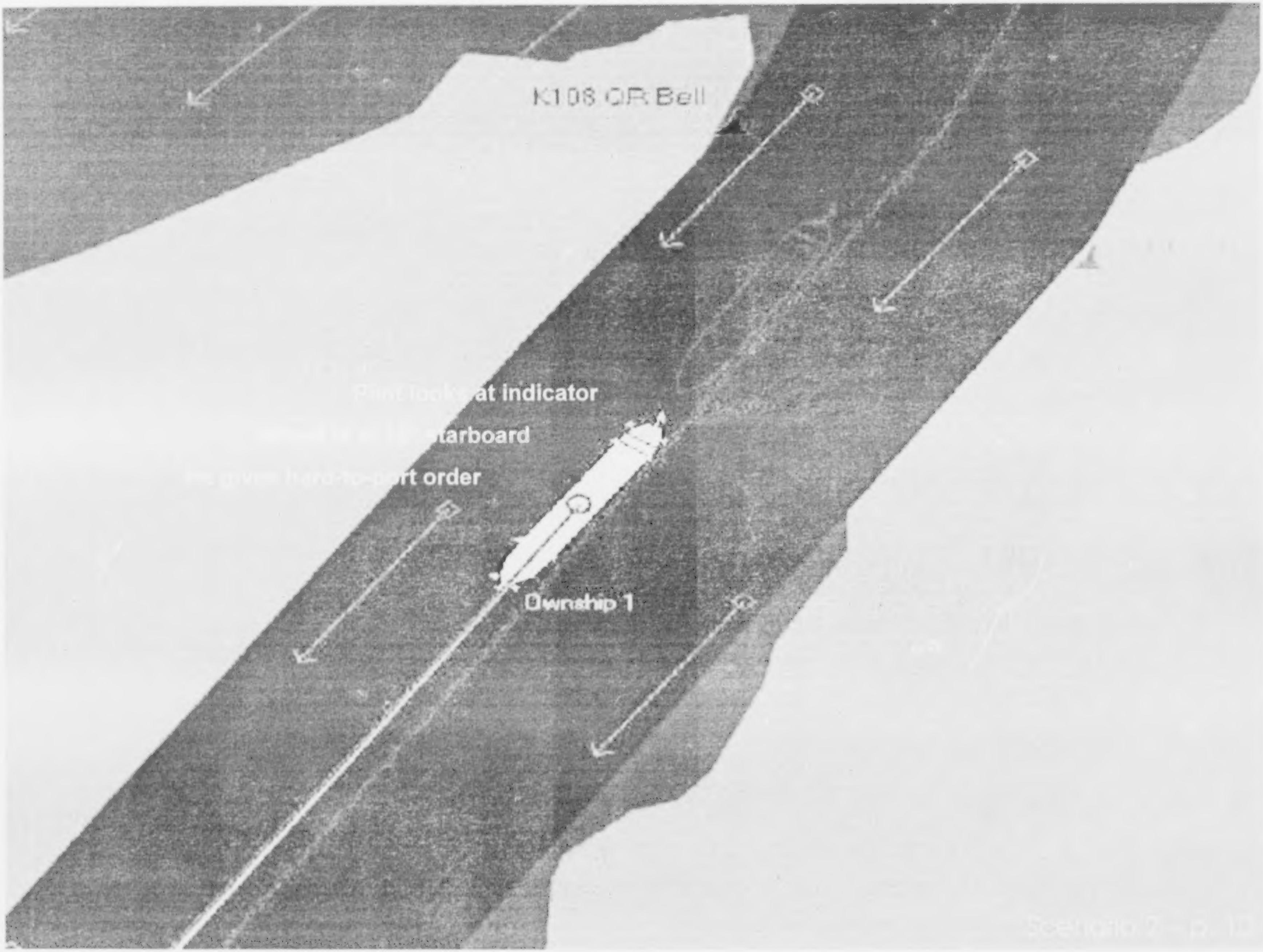

Wheel 15° starboard
Ownship 1
K100 OR Bell
Heading [deg]
202.8
Speed [kn]
16.7
100 [%]
0.6
0.6
Rudder
s15.0

- As the vessel moves to the heading ordered, it veers slightly to starboard, and the helmsman turns the wheel to port 5°; the pilot verifies with a glance and sees the wheel positioned to port…
- Helmsman sets the wheel at zero, but there is still some turning to starboard
- Since he is using only the compass, visual landmarks do not show the helmsman that the vessel is turning

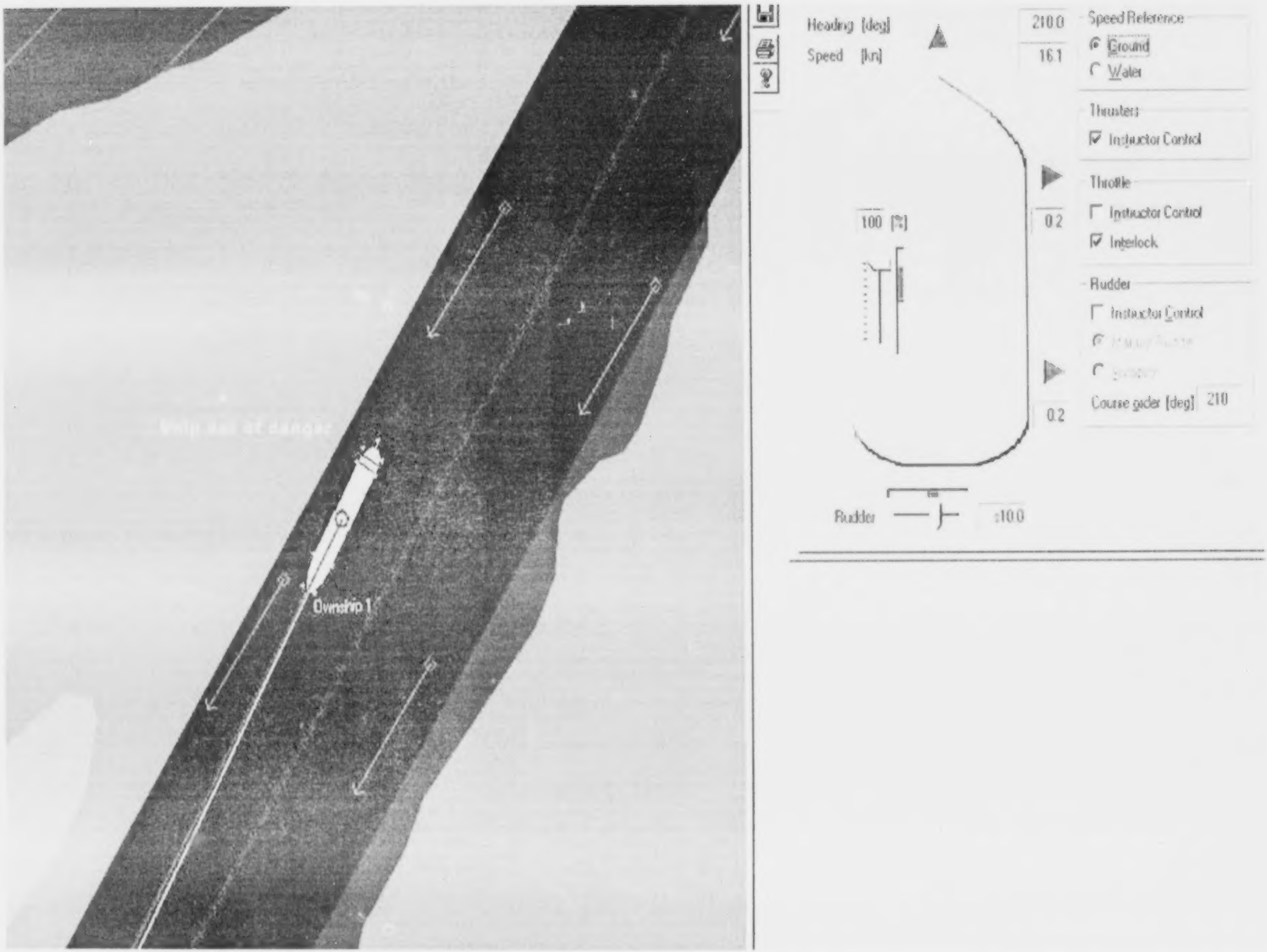

Wheel 5° port
K100 OR Bell
Pilot looks at Indicator
Ownship 1
Heading [deg]
212.9
Speed [kn]
15.0
100 [%]
0.1
0.1
Rudder
p5.0

- This is where an error can occur: the helmsman turns the wheel 5° to starboard instead of to port to stop the ship from turning, and not getting the desired result, he turns the wheel 15° to starboard…
- After a few seconds, the pilot sees what is happening and orders hard to port…
- The outcome may be that the ship strikes bottom on the north edge of the channel.




K108 QR Bell
Pilot looks at indicator
starboard
rt order
Ownship 1
Scenario 7

- At the course alteration point, the time is deemed to be zero
- From the time when course alteration is ordered to the time when the ship passes the ordered heading, 60 seconds elapse
- 10 seconds elapse between this time and the time when the wheel is turned starboard 15°. The hard-to-port order comes about 15 seconds later
- The ship is out of danger 1 minute and 15 seconds after the hard-to-port order is given
- The stern comes to within 100 feet of the edge of the channel
- If the wheel had been turned 20° instead of 15° to starboard, with the same 15 second delay, the ship would have touched the north edge of the channel
- Thus it's a matter of seconds that make the difference between a ship running aground or not



Heading [deg] 210.0
Speed [kn] 16.1

100 [%]
0.2
0.2
Rudder ±10.0

Speed Reference
● Ground
○ Water

Thrusters
☑ Instructor Control

Throttle
☐ Instructor Control
☑ Interlock

Rudder
☐ Instructor Control
● [illegible]
○ [illegible]
Course gider [deg] 210

The normal practice when two pilots are assigned to a ship is as follows:

- The pilots relieve each other every hour, but at critical locations the second pilot pays close attention to what the first pilot and the helmsman are doing

- A second pilot could have spotted the error and corrective action could have been taken in time

- In the case we have been looking at, the ship was on alignment 024°/204° at the time of course alteration; after the change of course, it was on the other alignment (033½°/213½°)

- Why did the pilot, whose eyes were on the radar, not see the problem earlier?

- When he saw that the helmsman was going past the ordered heading, he glanced at the rudder angle indicator and it showed 5° to port, which was the correct side

- The course over ground was 213½ °; the radar image may have momentarily given him a false sense of security because with 213½°, the heading marker was aligned with the centre of the channel

- Seeing increased turning to starboard, he reacted quickly to bring the ship back on course

- Why did the officer of the watch not see the problem in time?
  - Simply because of an accumulation of routine tasks and his lack of local knowledge

- The officer must plot the ship's position at regular intervals, BEFORE a change of course and immediately AFTER, and he must also make the appropriate entries in the log

- He has to supervise the helmsman, communicate with the lookout, monitor traffic, take care of radio communications, answers calls from the company, etc.

- Each of these tasks uses up a block of time that could otherwise have been used for watching

- In coastal waters, the officer has to perform these tasks safely while at the same time being on watch (which he does not have to do in pilotage waters)

There are ways of minimizing the risks associated with this type of situation

- Having a second pilot is one
- When the vessel has a big crew, good resource management is another way of reducing risk. This could mean having an extra officer on watch on the bridge whose sole task is to monitor manoeuvres
- His sole task would be to ensure that the manoeuvres are appropriate. But would this second officer have the local knowledge necessary to react in time?
- Are there enough officers for this sort of work? Are the officers sufficiently rested?

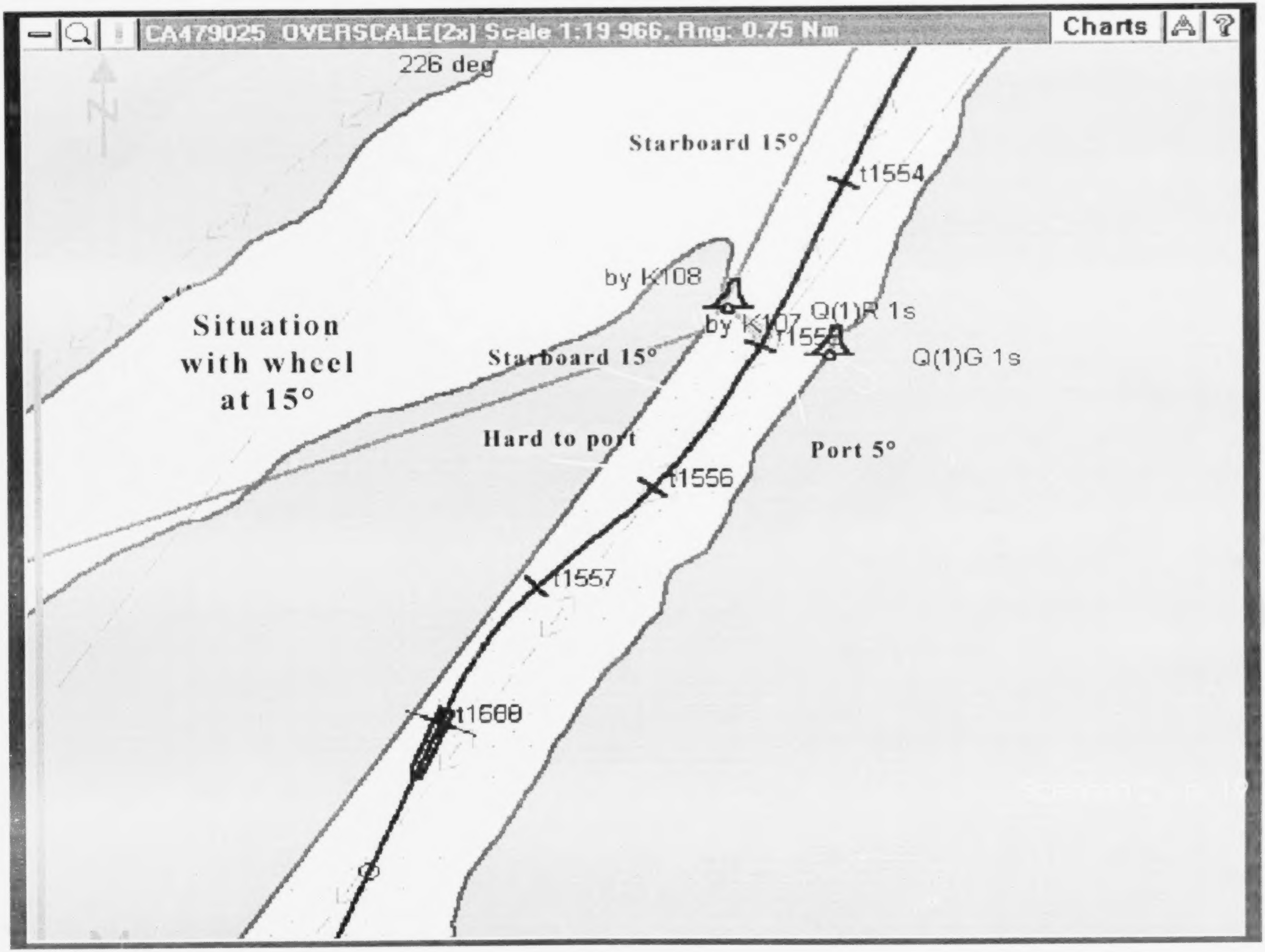
- If there had been downbound traffic, this situation could have led to grounding, since the bulker would have been well to the north of the indicated course.

- Could an ECDIS take the place of a second person?

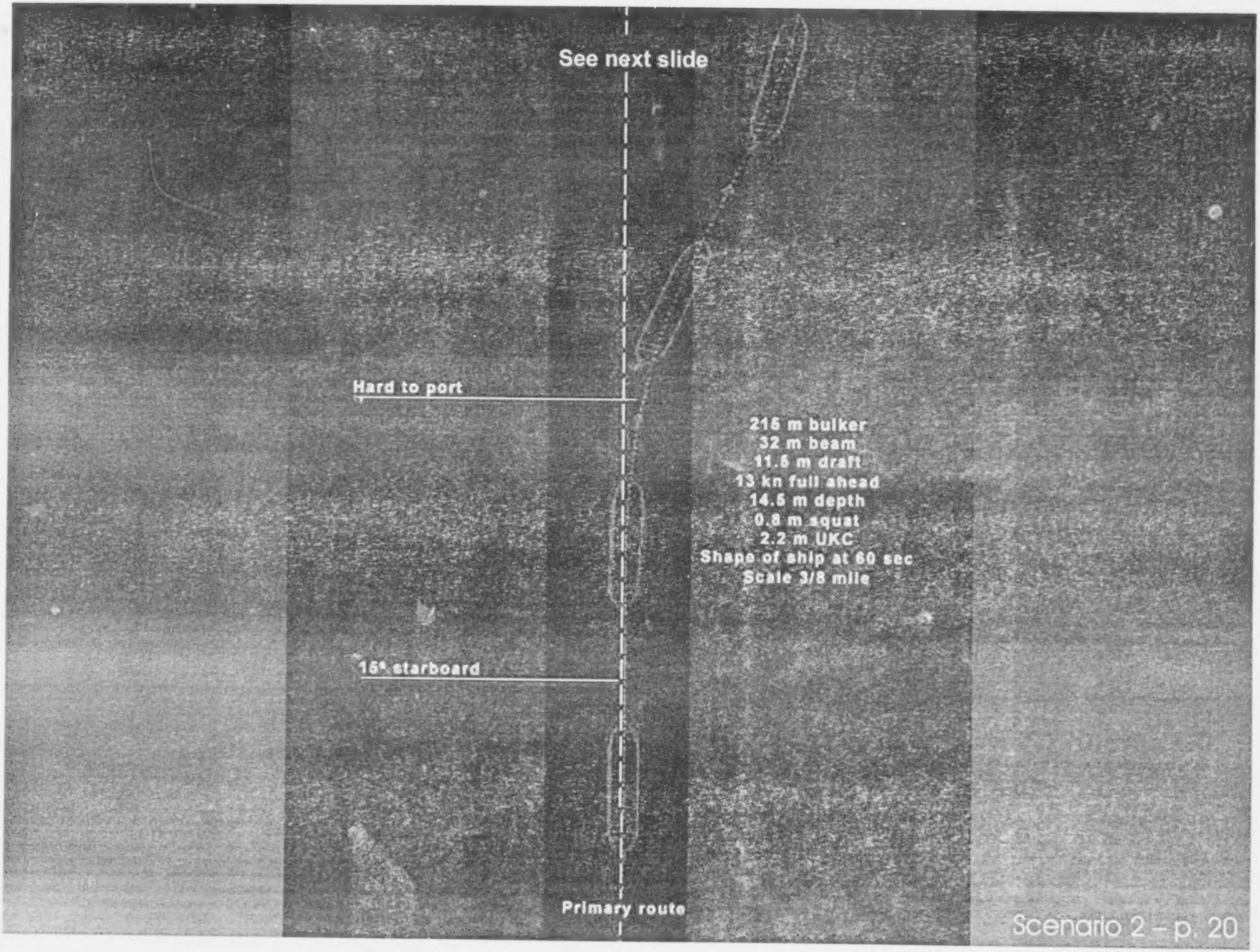
- An ECDIS is a system that displays electronic navigation charts in S-57 format on a screen of regulation size

- Using an ECDIS instead of paper charts, and in compliance with all IMO operating standards, calls for ongoing monitoring by a qualified person when in confined waters or pilotage waters

# Now let's rerun this scenario with the wheel at 15° and then at 20°



Situation
with wheel
at 15°



See next slide

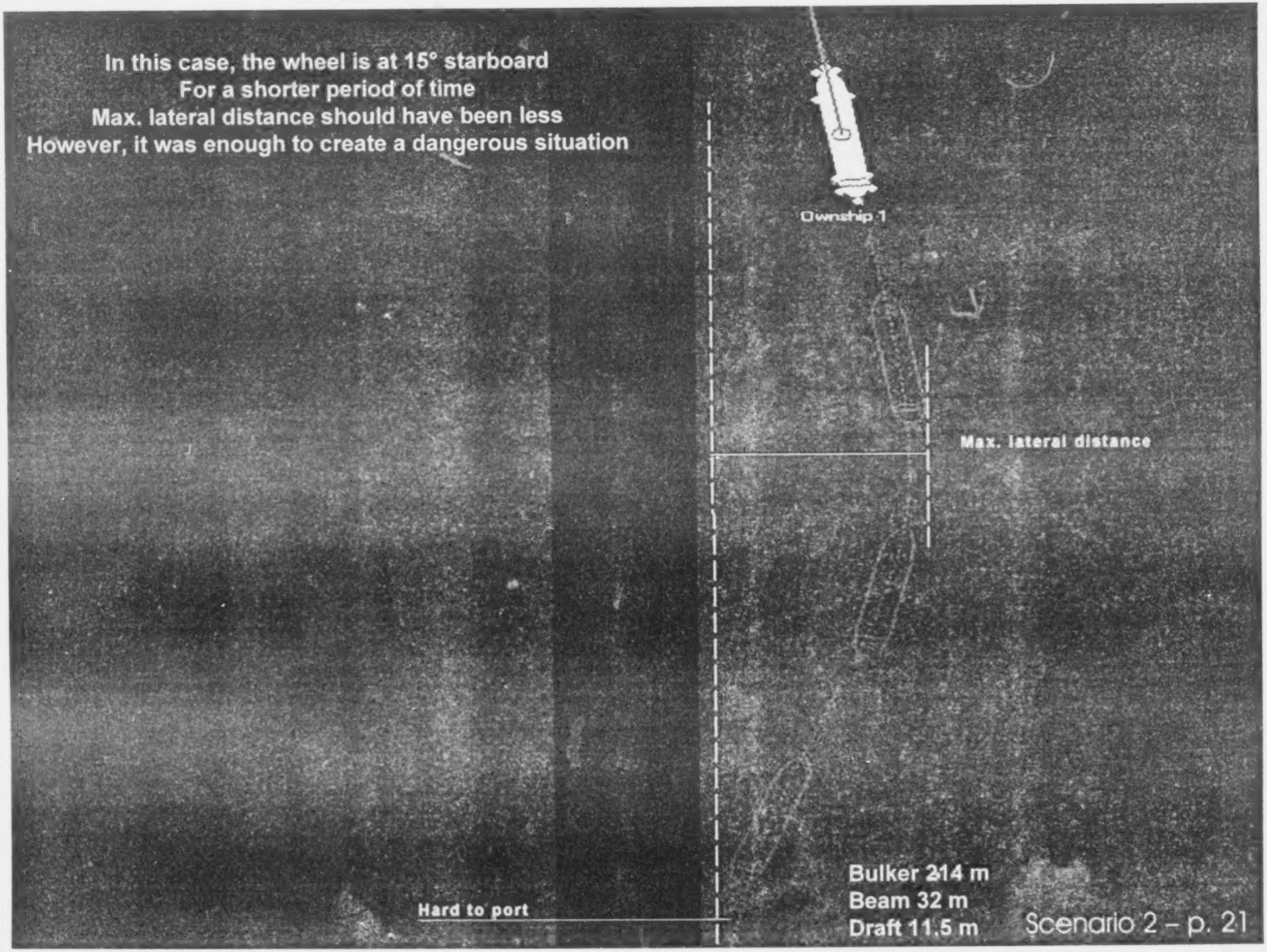
Hard to port

215 m bulker
32 m beam
11.5 m draft
13 kn full ahead
14.5 m depth
0.8 m squat
2.2 m UKC
Shape of ship at 60 sec
Scale 3/8 mile

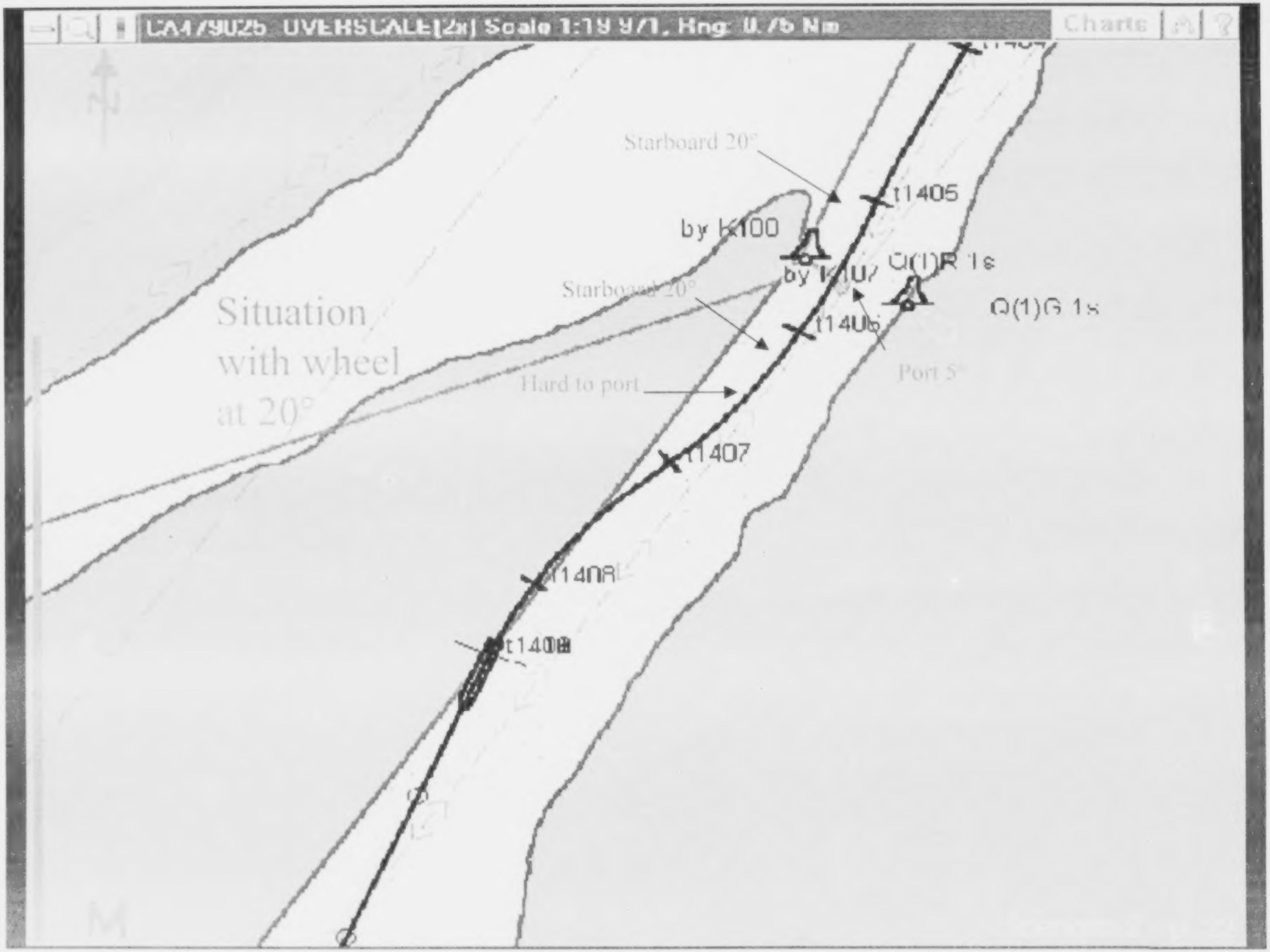
15° starboard

Primary route

In this case, the wheel is at 15° starboard
For a shorter period of time
Max. lateral distance should have been less
However, it was enough to create a dangerous situation



Bulker 214 m
Beam 32 m
Draft 11.5 m



Situation with wheel at 20°

# Scenario 3

## Positioning error

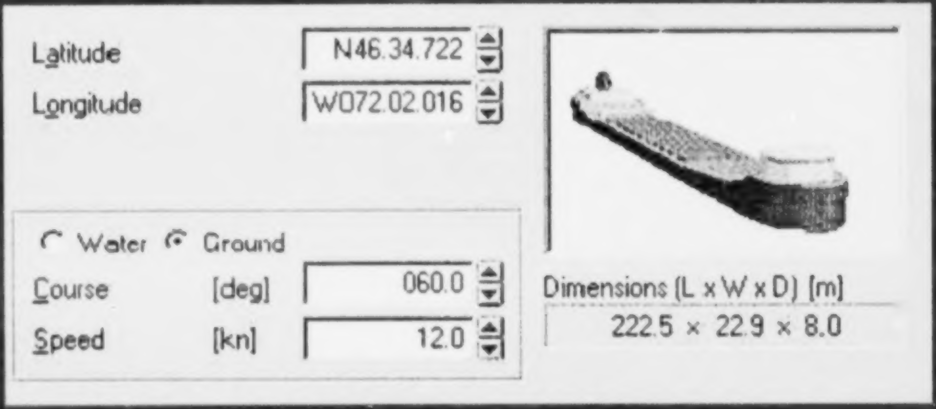
# Human error and possible consequences in confined waters

## Scenario 3

## Positioning error

# Ship: Bulker

- Length: 223 metres
- Beam: 23 metres
- Displacement: 34,000 cubic metres
- Max. forward speed: 14 knots
- Max. reverse speed: 7 knots
- Engine: 5860 kW
- Draft forward: 8 m
- Draft aft: 8 m



Latitude N46.34.722

Longitude W072.02.016

○ Water ● Ground

Course [deg] 060.0

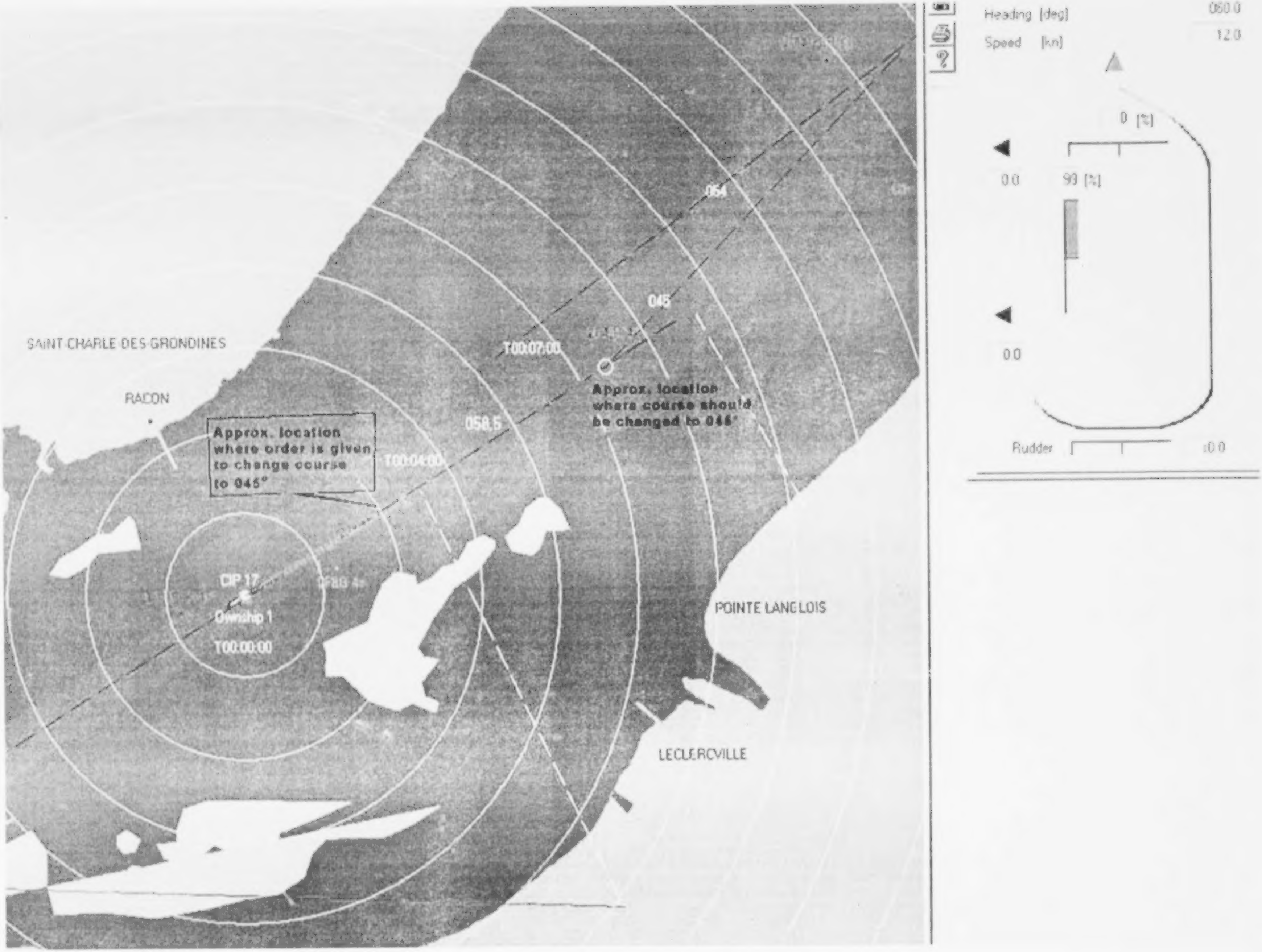
Speed [kn] 12.0

Dimensions (L x W x D) [m]

222.5 × 22.9 × 8.0

# Hypothetical situation

- Ship downbound at Call In Point 17, Grondines dock
- Speed through water 12 knots
- Gyrocompass heading 060°; range lights off on the stern
- Good visibility
- Tide: high slack changing to ebb
- No traffic in the area



Approx. location where order is given to change course to 045°

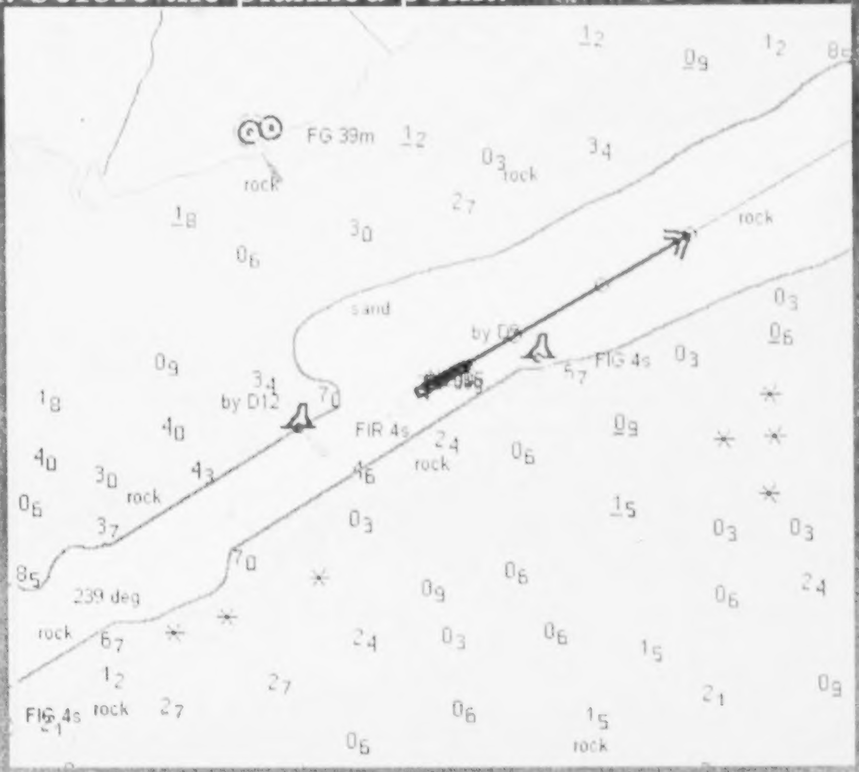
Approx. location where course should be changed to 045°

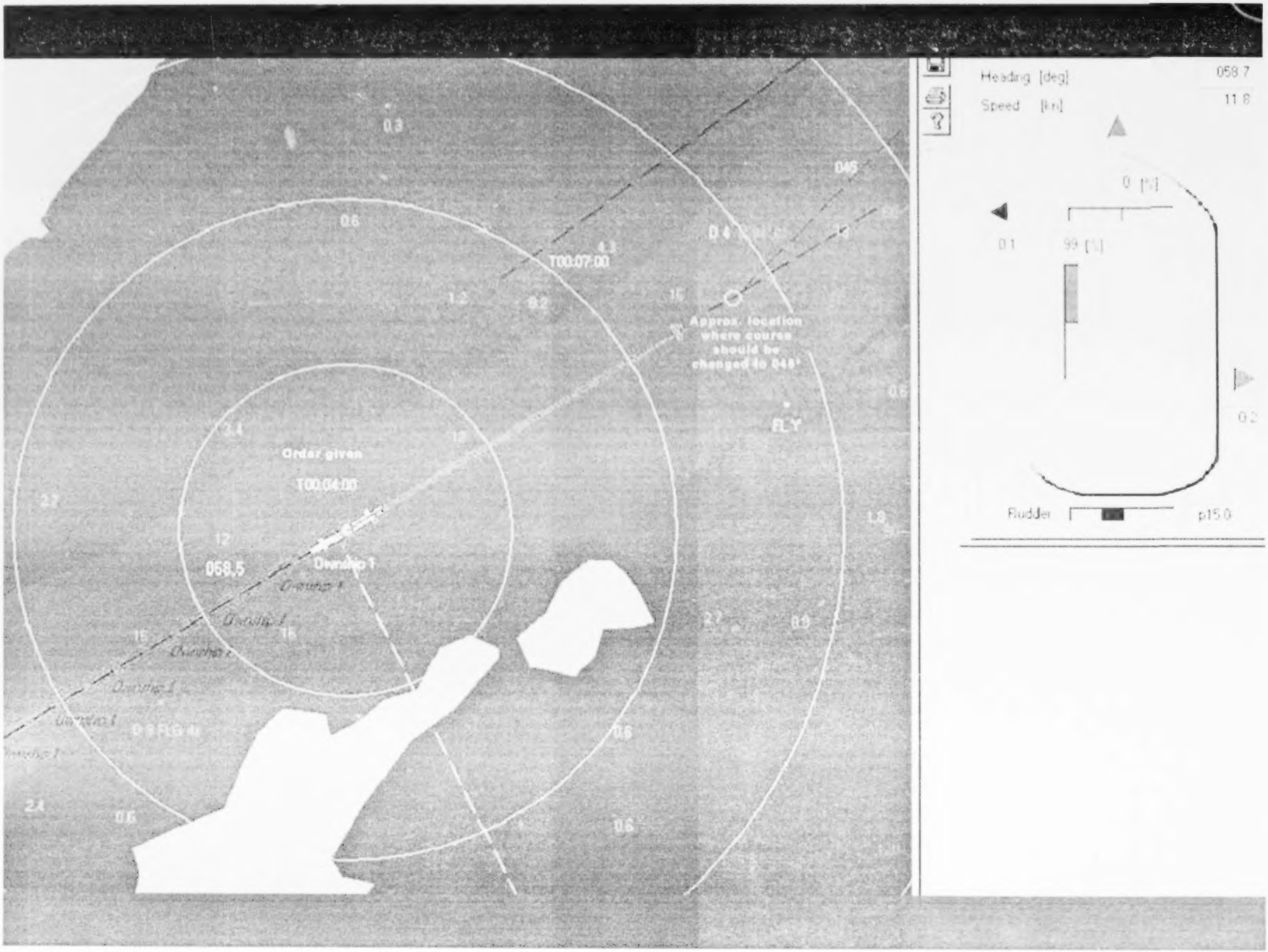
# Sequence of events

- At T00:00:00, the ship reports to VTS as per the normal procedure
- The officer of the watch takes a radar bearing and range, and goes to the chart table to plot the position, make an entry in the ship's log, and record the call in the radio log
- At about T00:04:00, the pilot orders a change of course to 045°

# This is where the first event in the error chain occurs

- For some reason, the pilot gave the order to change course at the wrong location, ¾ n.m. before the planned point.





Heading [deg] 058.7

Speed [kn] 11.8

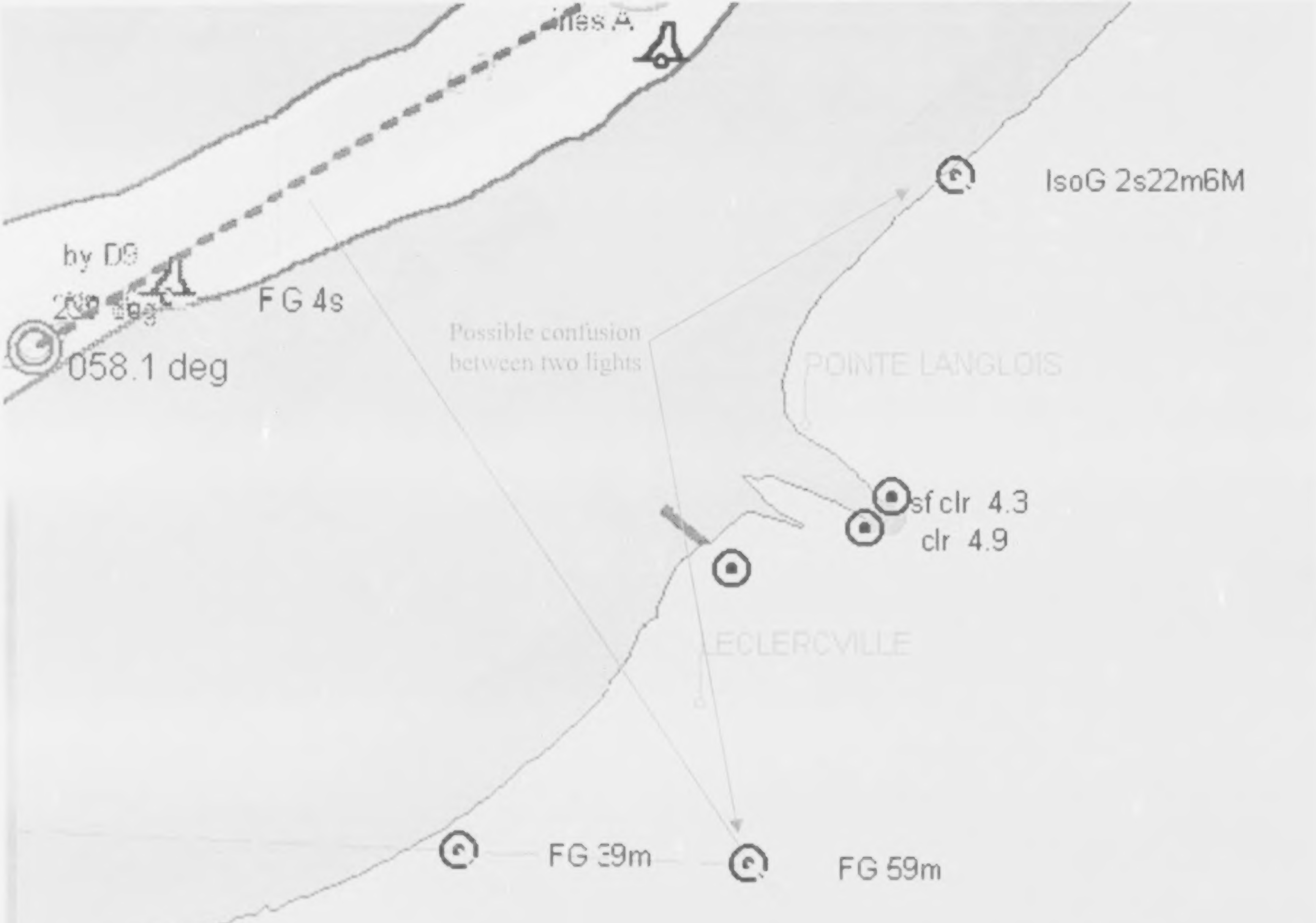
Rudder p15.0

# The second event in the error chain occurs as a result of the mandatory tasks performed by the officer of the watch

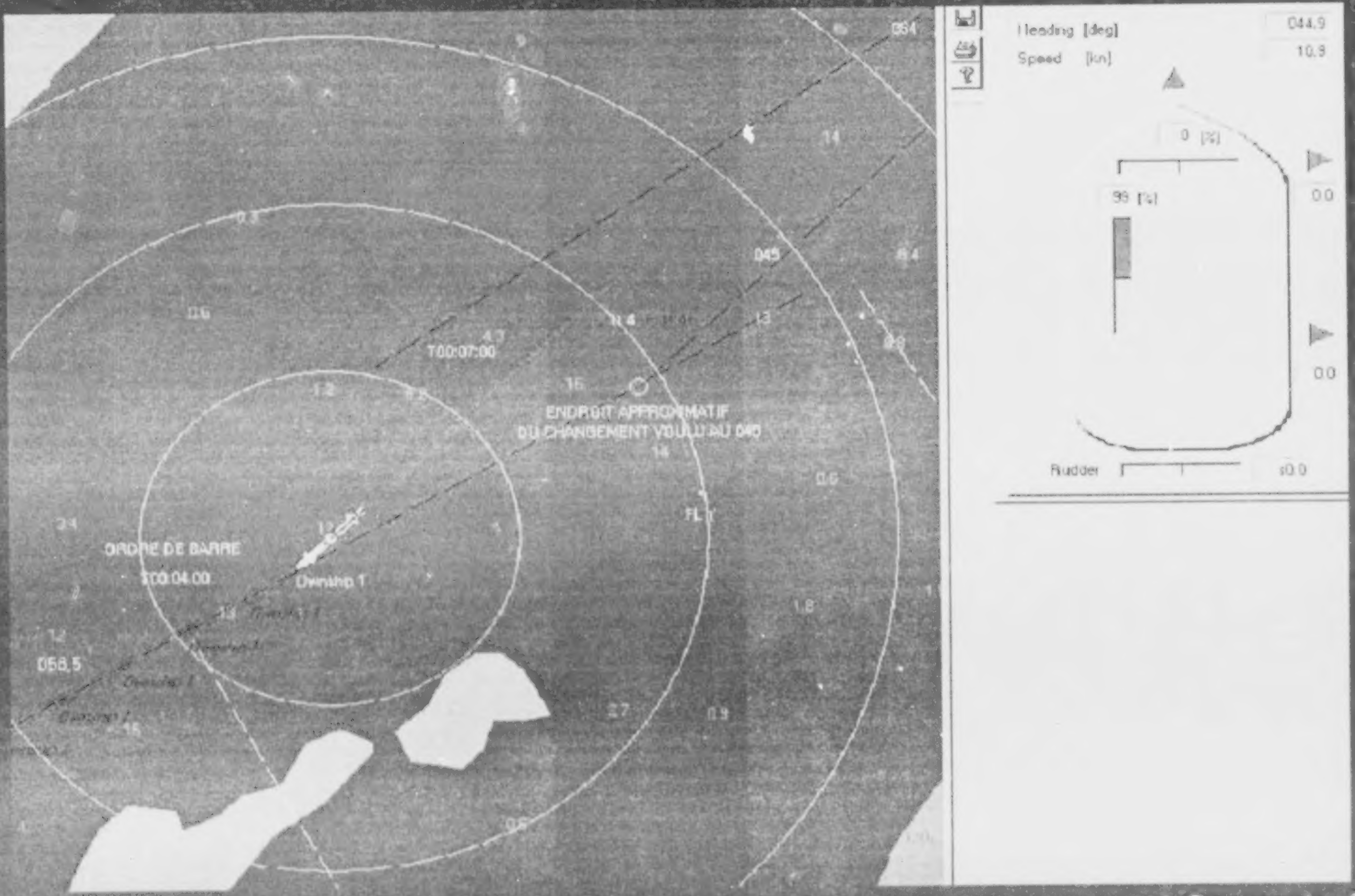
- The officer of the watch does the same thing he did a few minutes before:
  - He takes a radar bearing and range, and goes to the chart table to plot the position, make an entry in the ship's log, and record the call in the radio log
- The time to perform these routine tasks is about 2.5 minutes (verifiable)
- When the officer comes back on watch, the ship is no longer at the position marked but about 0.5 miles east of that position
- In such a situation, the officer would have had no chance to react in time

The third event could be a state of overconfidence, with the result that no verification of position is made immediately after the course alteration.

- We may speculate that momentary confusion between two lights of the same colour was the initial cause of error
- Looking at the marine chart in the next slide, we see that both lights are green
- However, they have different characteristics
- Someone who took only a quick glance could be led into error
- Characteristics of the first light: FG
- Characteristics of the second light: IsoG 2s
- Fatigue could be an aggravating element in such a case

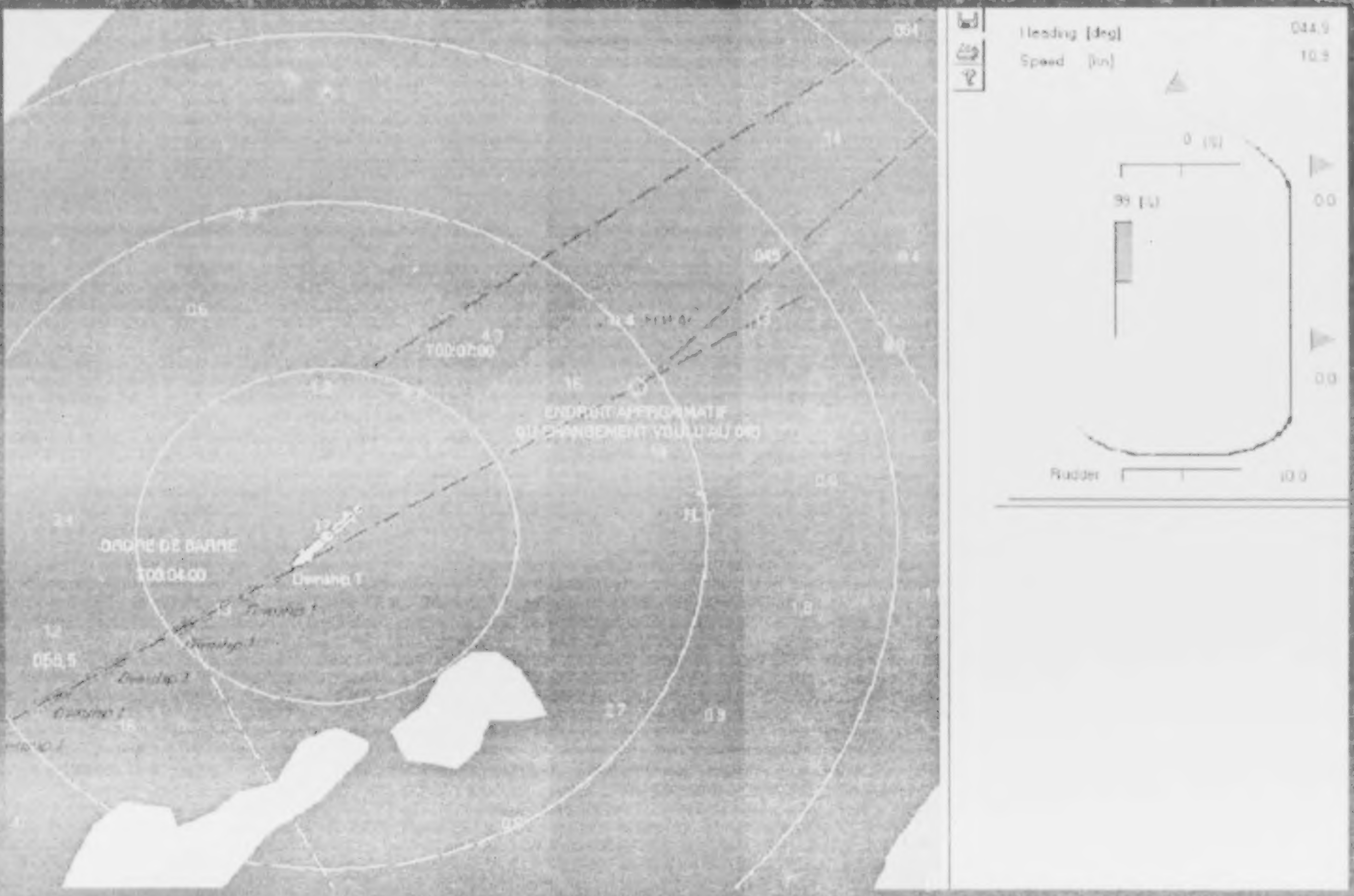

ines A
by D9
239 deg
F G 4s
058.1 deg
IsoG 2s22m6M
Possible confusion between two lights
POINTE LANGLOIS
sf clr 4.3
clr 4.9
LECLERCVILLE
FG 39m
FG 59m

# Let's continue with the scenario and look at the hypothetical movement of the vessel

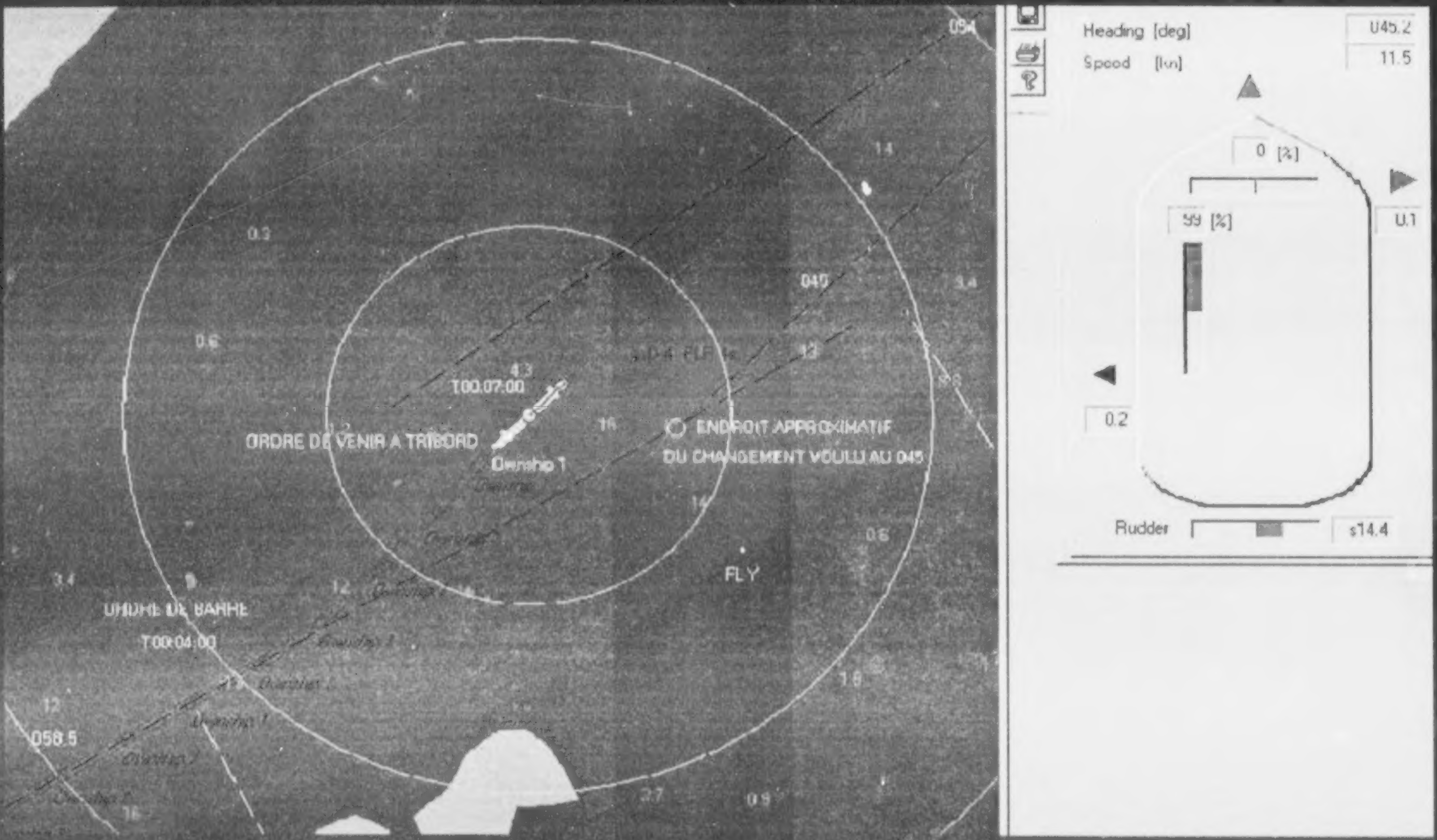


MARITIME INNOVATION

# Let's continue with the scenario and look at the hypothetical movement of the vessel

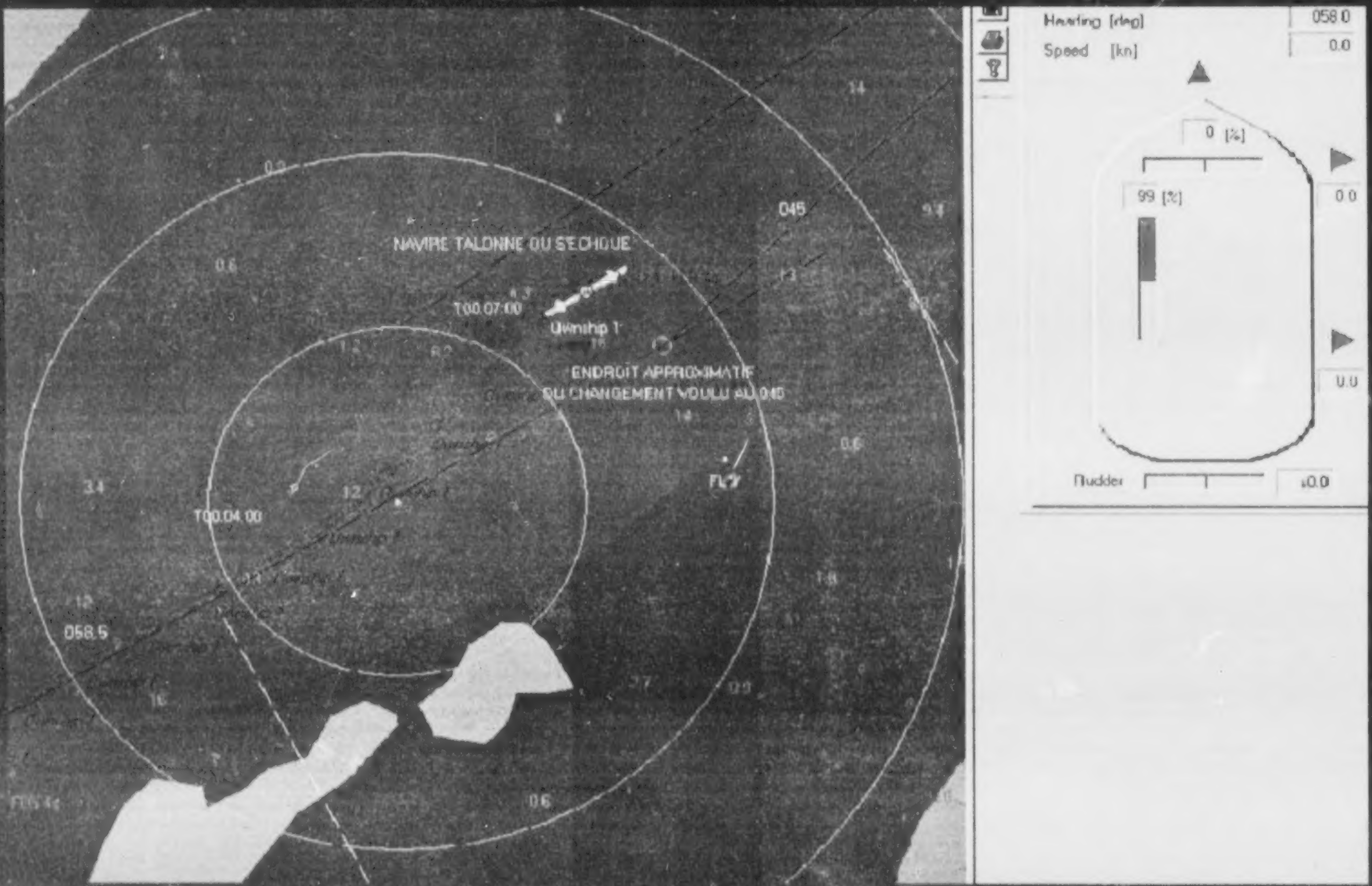


# Order to turn to starboard

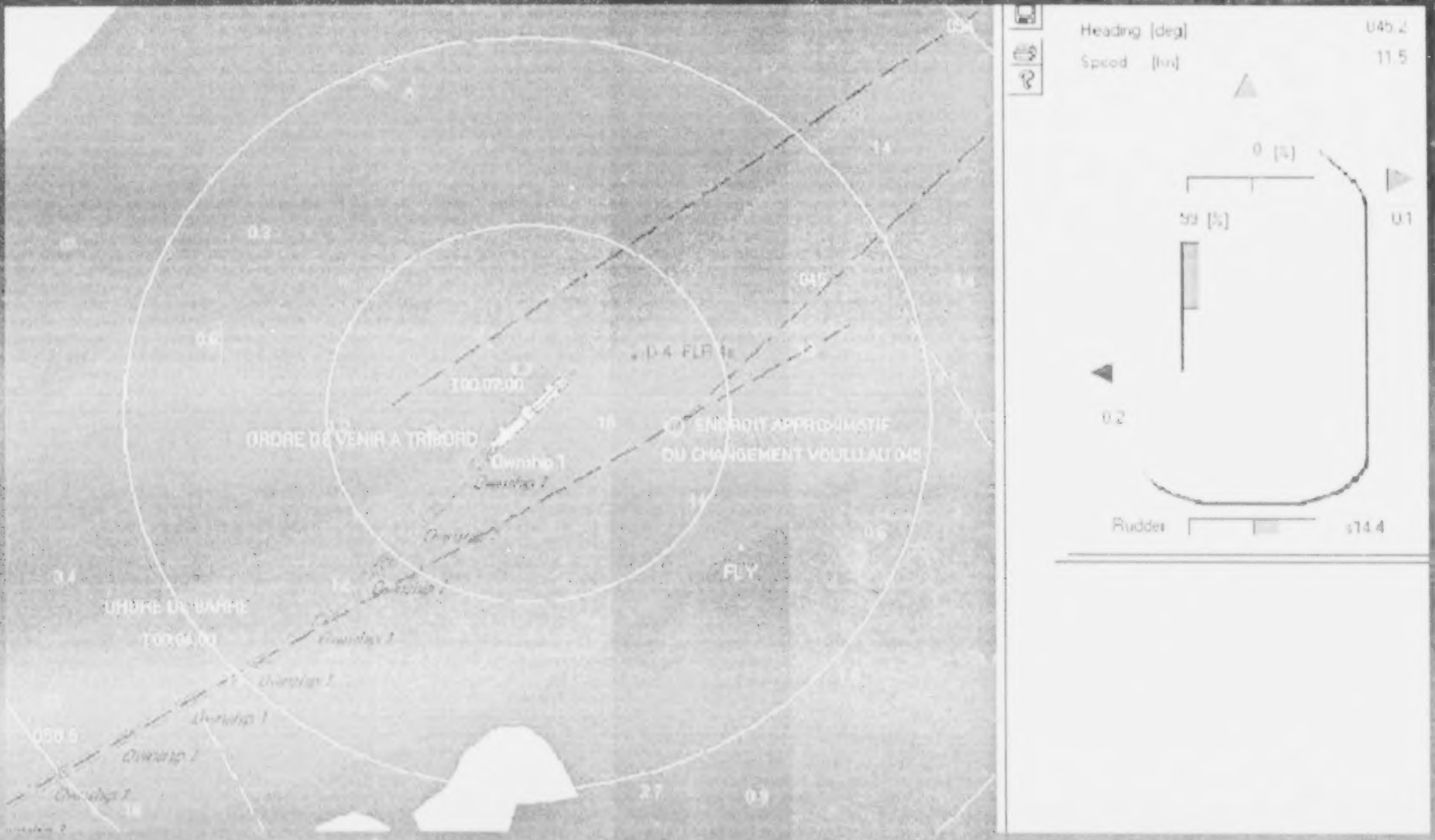


MARITIME INNOVATION

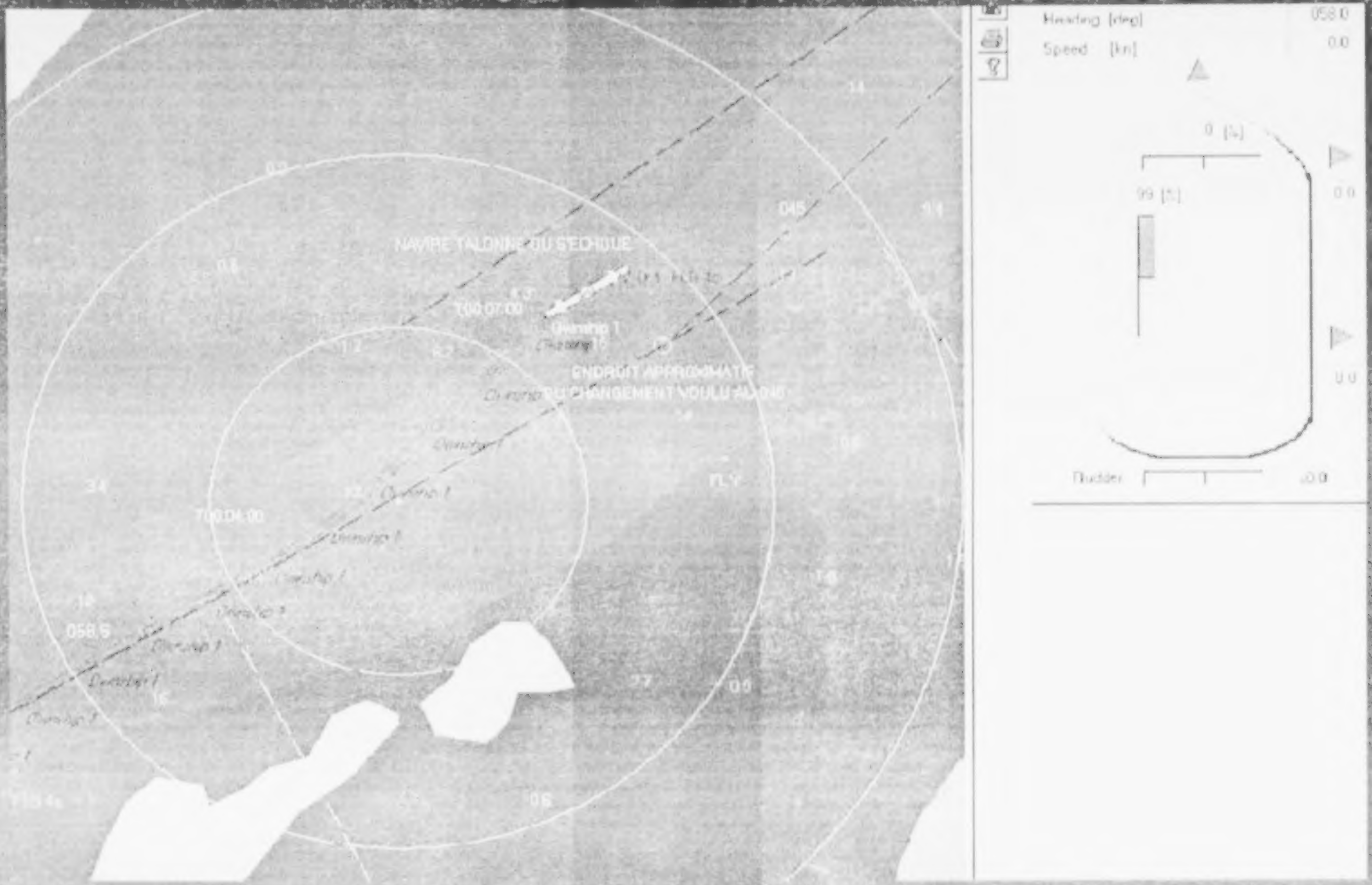
# Outcome despite manoeuvre



# Order to turn to starboard



# Outcome despite manoeuvre



# What mitigation measures can be considered?

- Having a second pilot is one possible measure:
    - The pilots relieve each other every hour, but at critical locations the second pilot pays close attention to what the first pilot and the helmsman are doing
    - A second pilot could have spotted the error and corrective action could have been taken in time

- When the vessel has a big crew, good resource management is another possible mitigation measure: have an extra officer on watch on the bridge whose sole task is to monitor manoeuvres

- His sole task would be to ensure that the manoeuvres are appropriate. But would this second officer have the local knowledge necessary to react in time?

- Are there enough officers for this sort of work? Are the officers sufficiently rested?

# This leads to the following question:

- Could an ECDIS take the place of a second person?

- An ECDIS is a system that displays electronic navigation charts in S-57 format on a screen of regulation size

- Using an ECDIS instead of paper charts, and in compliance with all IMO operating standards, calls for ongoing monitoring by a qualified person when in confined waters or pilotage waters

# Scenario 4

# Misinterpretation of navigating conditions

# Human Error and Possible Consequences in Confined Waters

## Scenario 4

## Misinterpretation of navigating conditions

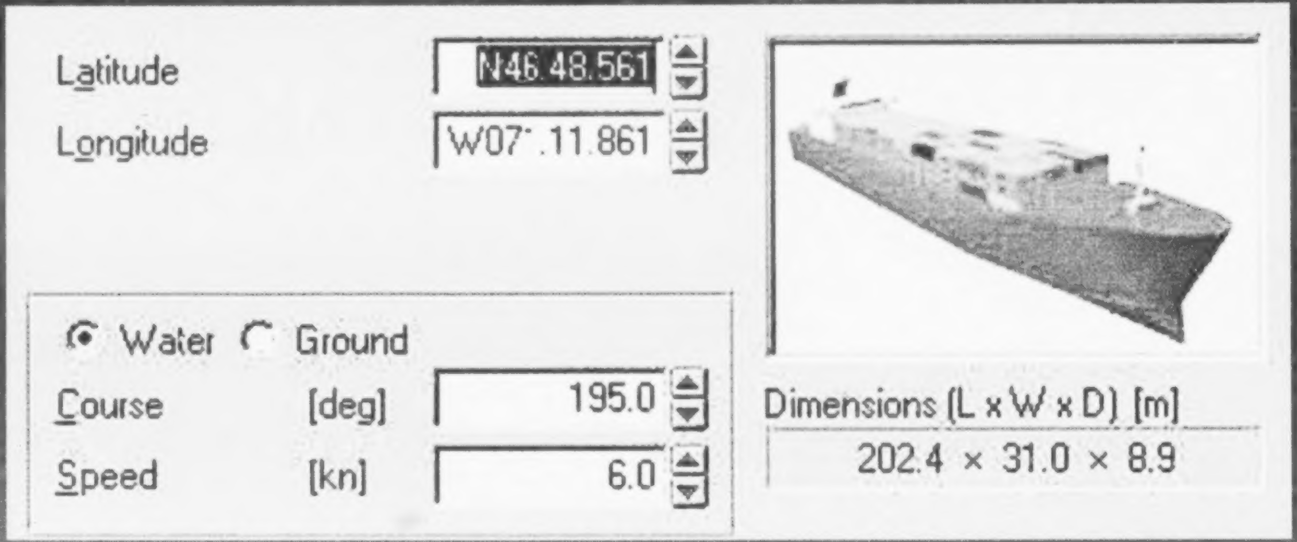
MARITIME INNOVATION

ROBERT
HAMELIN
& associés

# Carrier: container ship

- Loaded 294 m ship
- Beam:. 32.2 m
- Displacement: 74,700 cubic metres
- Draft forward: 10 m
- Draft aft: 10 m

- When fully loaded, draft 12.5 m
- Max. forward speed: 28 knots
- Max. reverse speed: 7.5 knots
- Engine: 48,640 kW



Latitude N46.48.561

Longitude W07° .11.861

● Water ○ Ground

Course [deg] 195.0

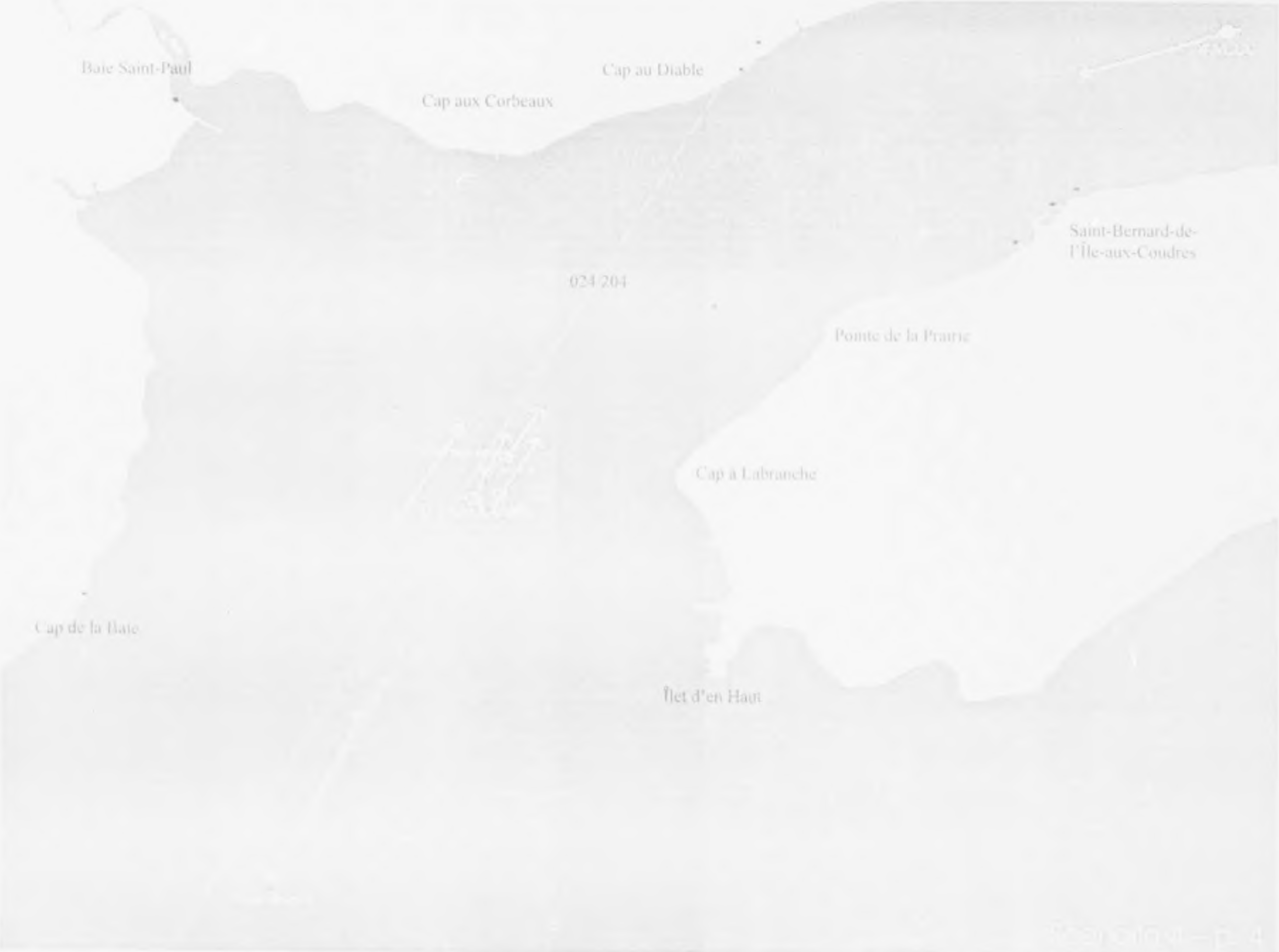
Speed [kn] 6.0

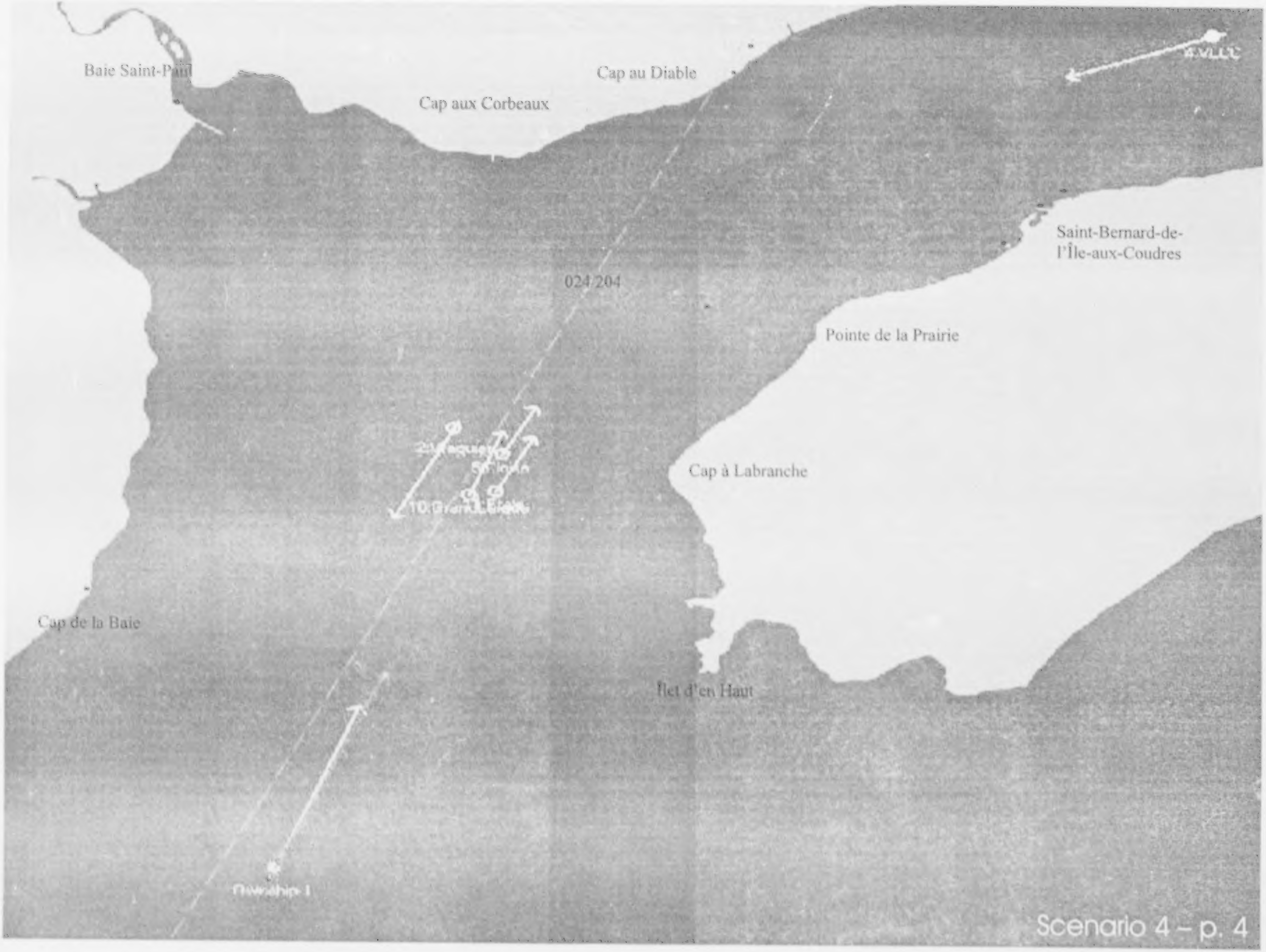
Dimensions (L x W x D) [m]

202.4 × 31.0 × 8.9

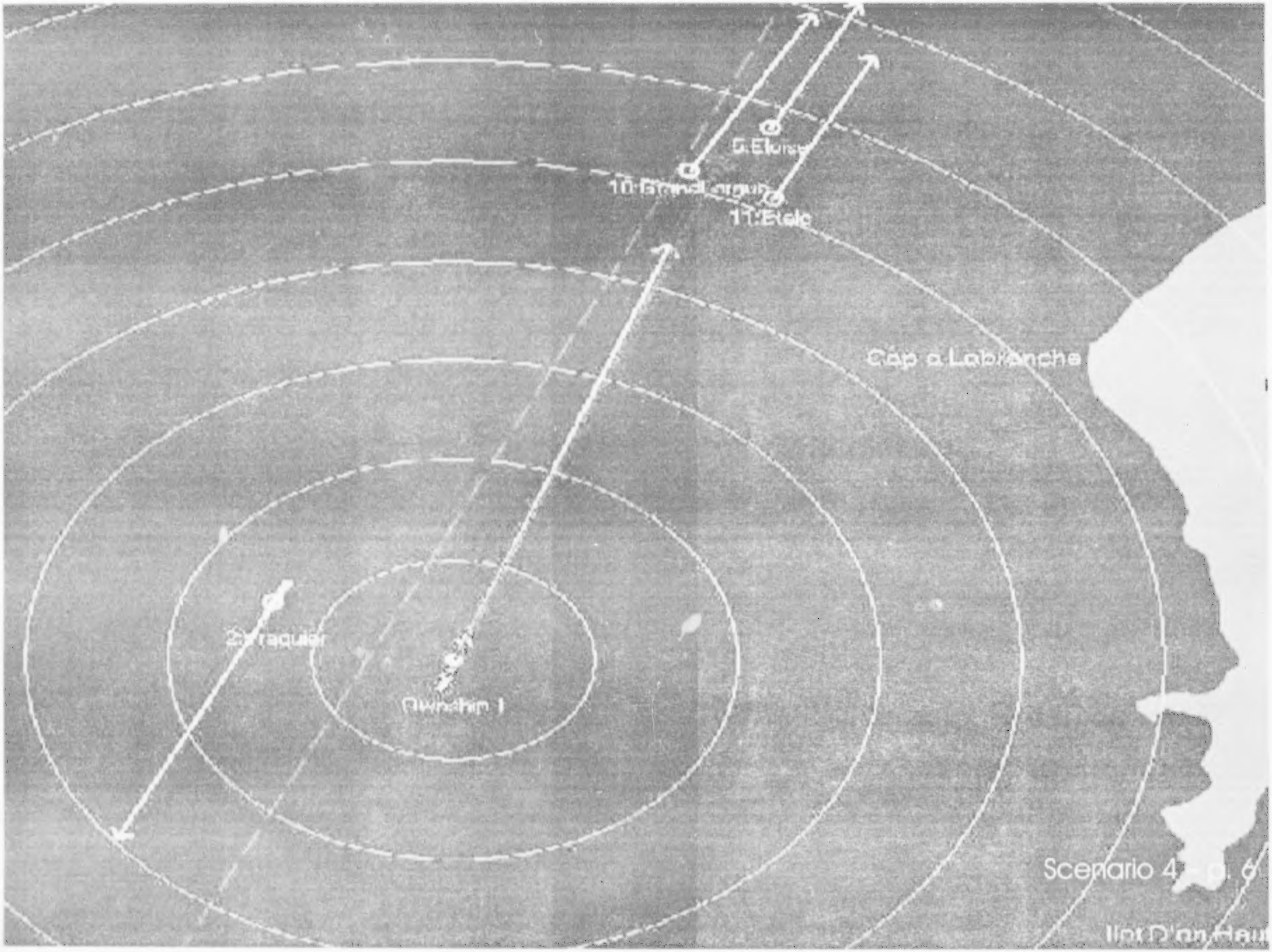
# Hypothetical situation

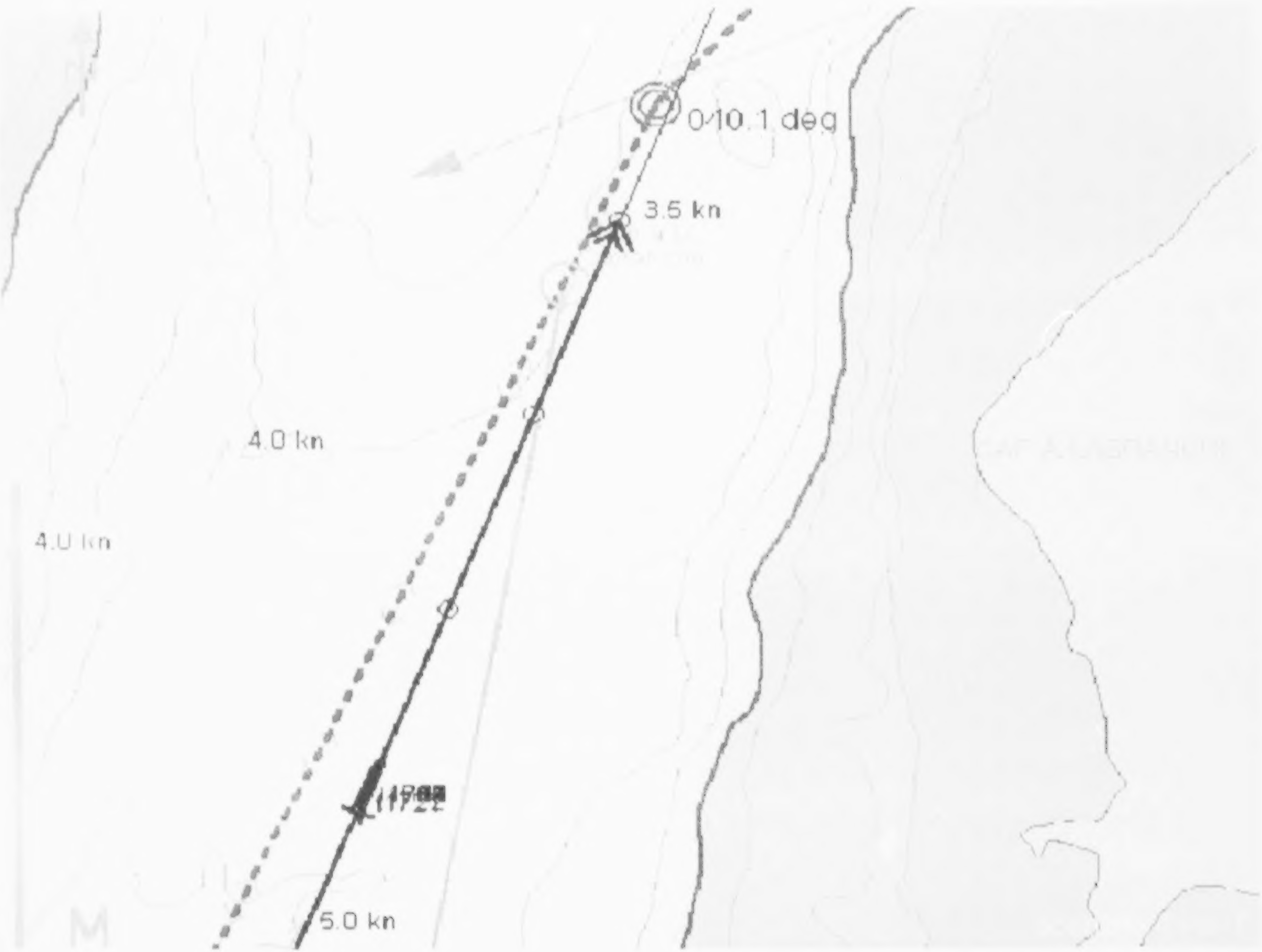
- Ship downbound at Cap de la Baie
- Slowsteaming (*manœuvre*) 18 knots
- Visibility 5-7 miles diminishing during rain showers, moderate SSW wind increasing
- Tide low at Pointe-au-Père, strong ebb current
- Bulker upbound at Cap à Labranche
- VLCC upbound at Saint-Joseph
- Three sailboats heading toward Saint-Bernard for shelter


Baie Saint-Paul
Cap aux Corbeaux
Cap au Diable
Saint-Bernard-de-
l'Île-aux-Coudres
024 204
Pointe de la Prairie
Cap à Labranche
Cap de la Baie
Îlet d'en Haut


Baie Saint-Paul
Cap aux Corbeaux
Cap au Diable
4:VLCC
Saint-Bernard-de-
l'Île-aux-Coudres
024/204
Pointe de la Prairie
Cap à Labranche
Cap de la Baie
Îlet d'en Haut

- The pilot contacts the bulker, which says it is keeping to the north
- The pilot contacts the VLCC, which says it will be slightly to the north of centre at Pointe de la Prairie
- The pilot of the VLCC also says he will start to move slowly starboard before crossing the alignment and will end up at 204, two cables north of the alignment
- The encounter with the bulker goes without a hitch, each ship being to the right of the alignment (one upbound, one downbound)
- The pilot's attention turns to the sailboats; he has contacted them and knows they are heading toward Saint-Bernard


5:Eloise
10:Grand Largue
11:Etoile
Cap a Lablanche
2:Traquier
Rwinshim 1
Scenario 4
Ilot D'en Hau

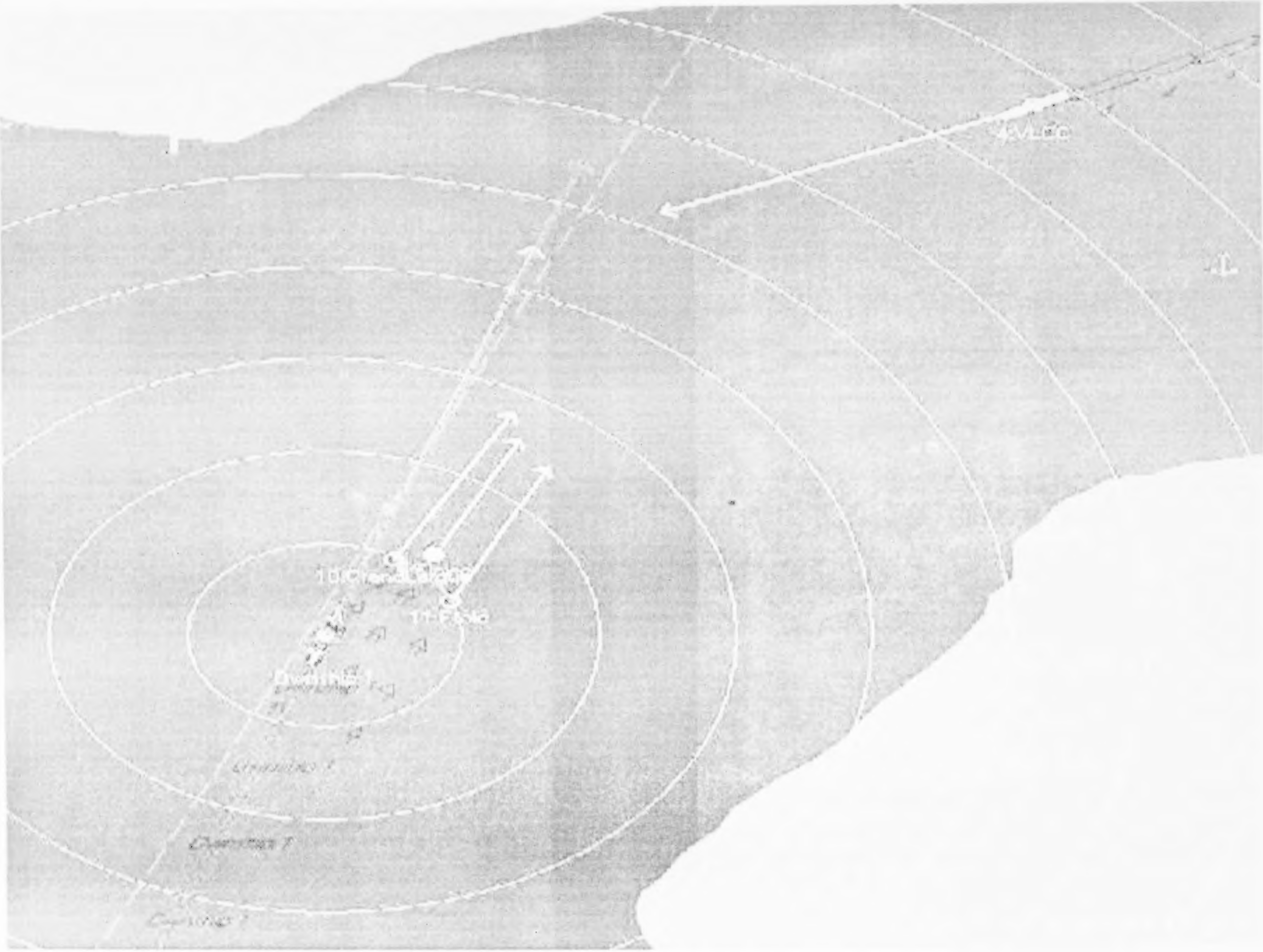

0/10.1 deg
3.5 kn
4.0 kn
4.0 kn
1172
5.0 kn
M

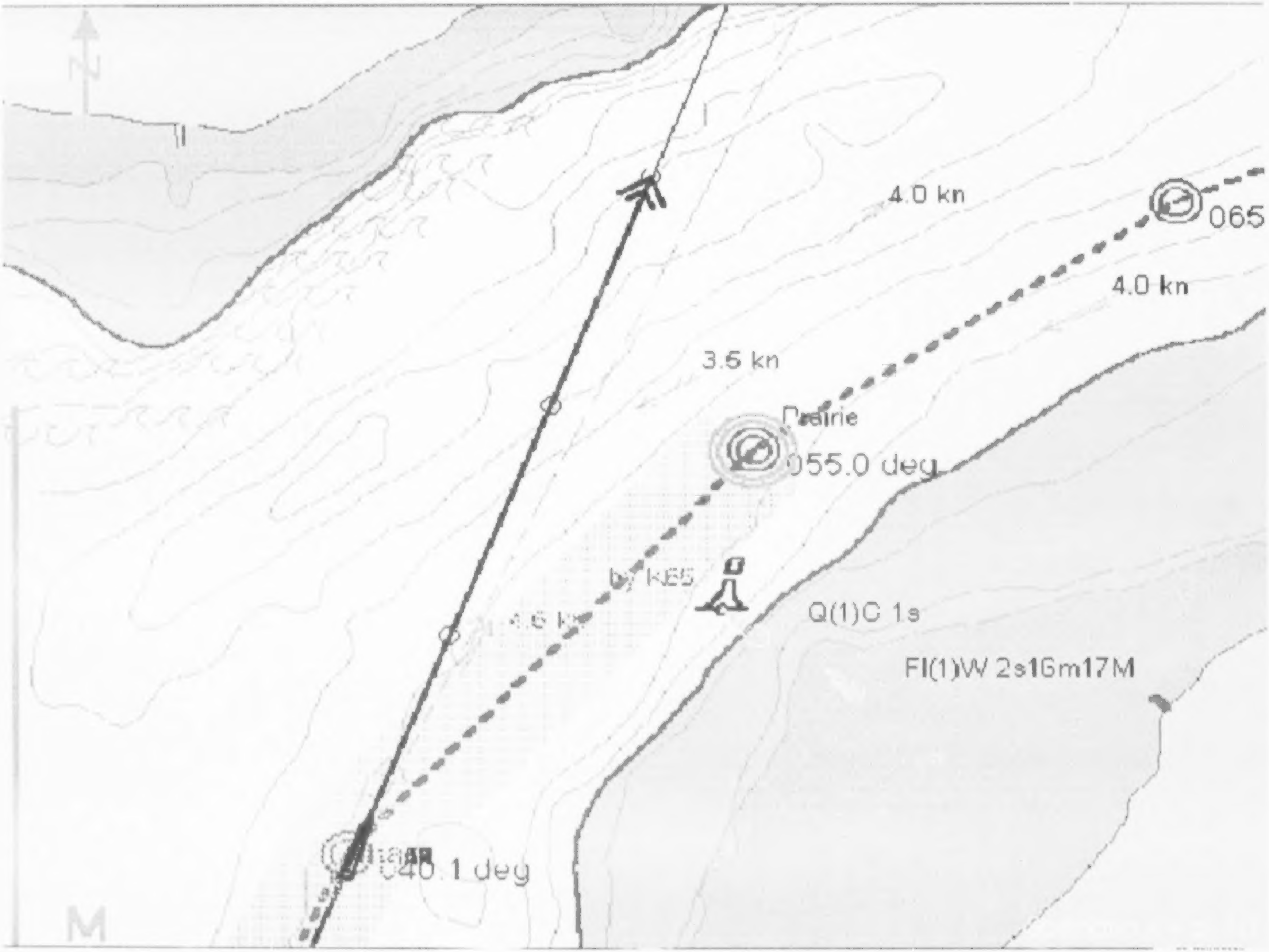
The pilot has to choose one of the following options:

- 1) Keep to the current heading and speed, overtake the sailboats on the north, and alter course at Prairie, making adjustments as dictated by the situation
- 2) Slow down to give the VLCC time to cross the Cap au Diable alignment, then return to original speed
- Let's assume he chooses the first option and so informs the watch officer, who agrees
- The pilot estimates that he should overtake the sailboats, which are visible to the naked eye, at the Prairie course alteration point to 040°
- However, once he arrives at the course alteration point, the closest sailboat is still forward of the beam to starboard

MARITIME INNOVATION

ROBERT HAMELIN & associés

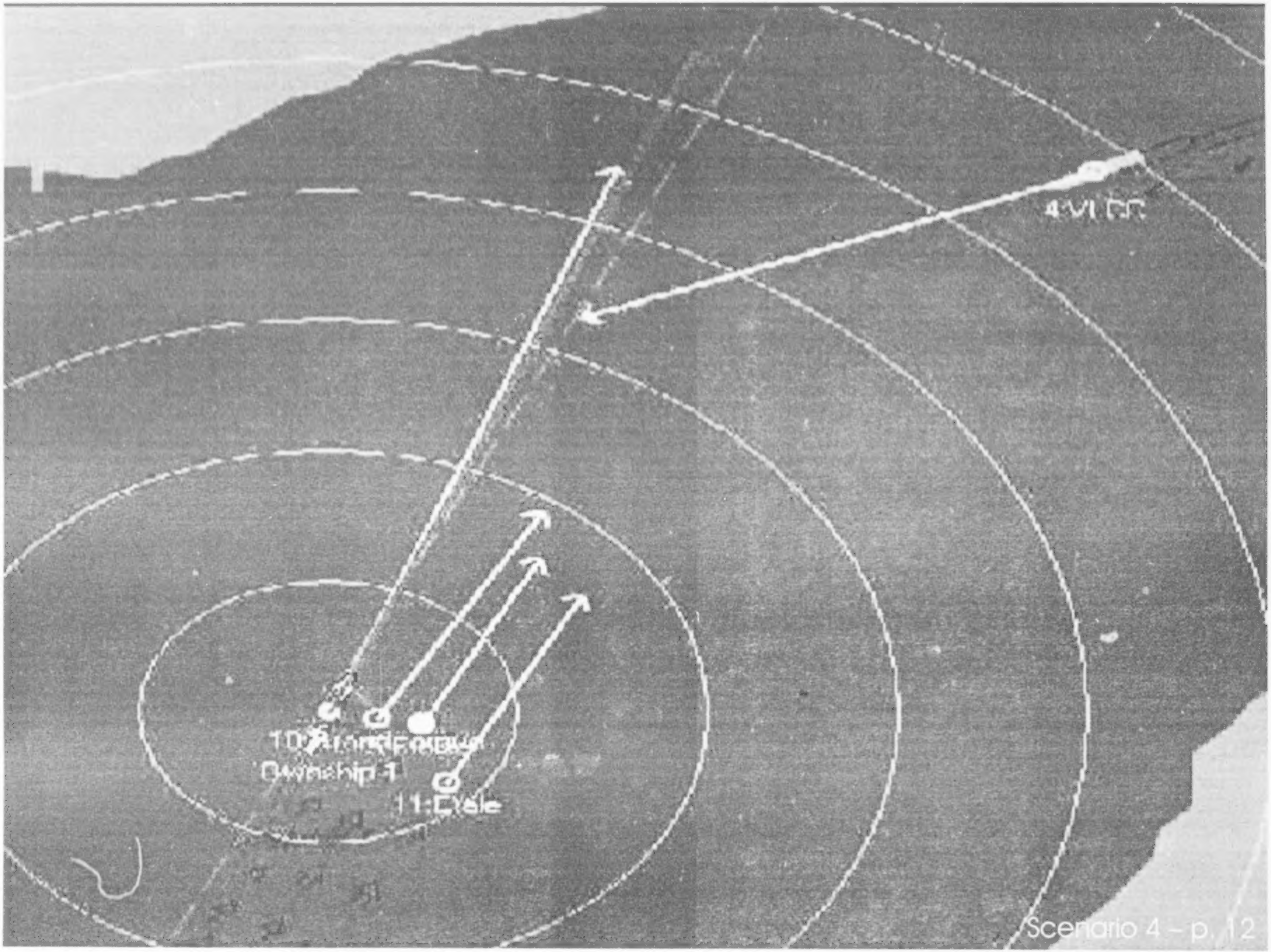


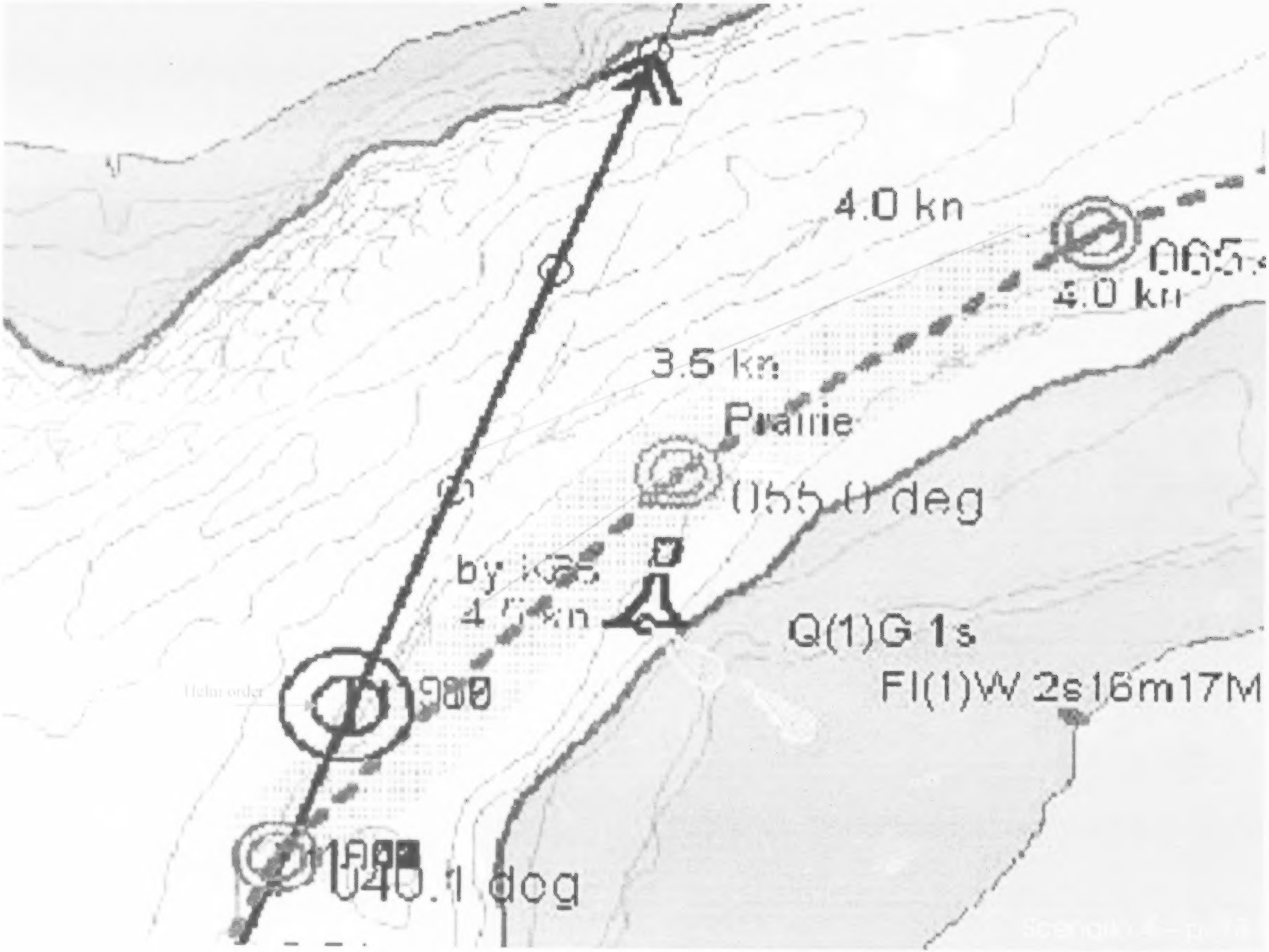

N
4.0 kn
065
4.0 kn
3.5 kn
Prairie
055.0 deg
by KB5
4.6 kn
Q(1)C 1s
Fl(1)W 2s16m17M
040.1 deg
M

- The pilot decides to wait until they are abeam to starboard before changing course at Prairie (second link in chain of events)

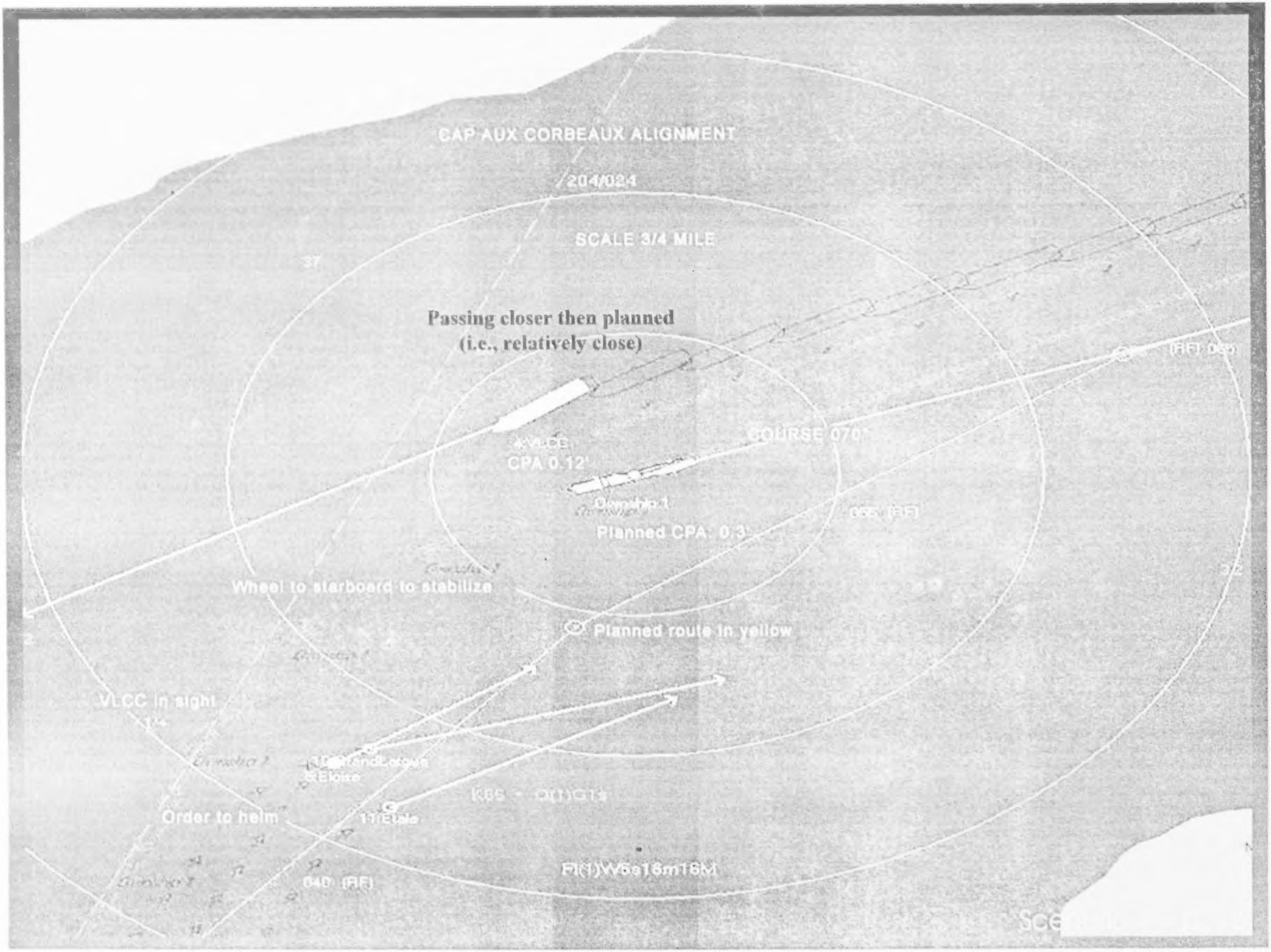
- When the sailboats are abeam starboard, the pilot orders the first change of course to 045° (040° over ground) (third link)

- Actually, the ship has passed the course alteration point and a change of heading to 70° should have been ordered (065° over ground), corresponding to the third change of course

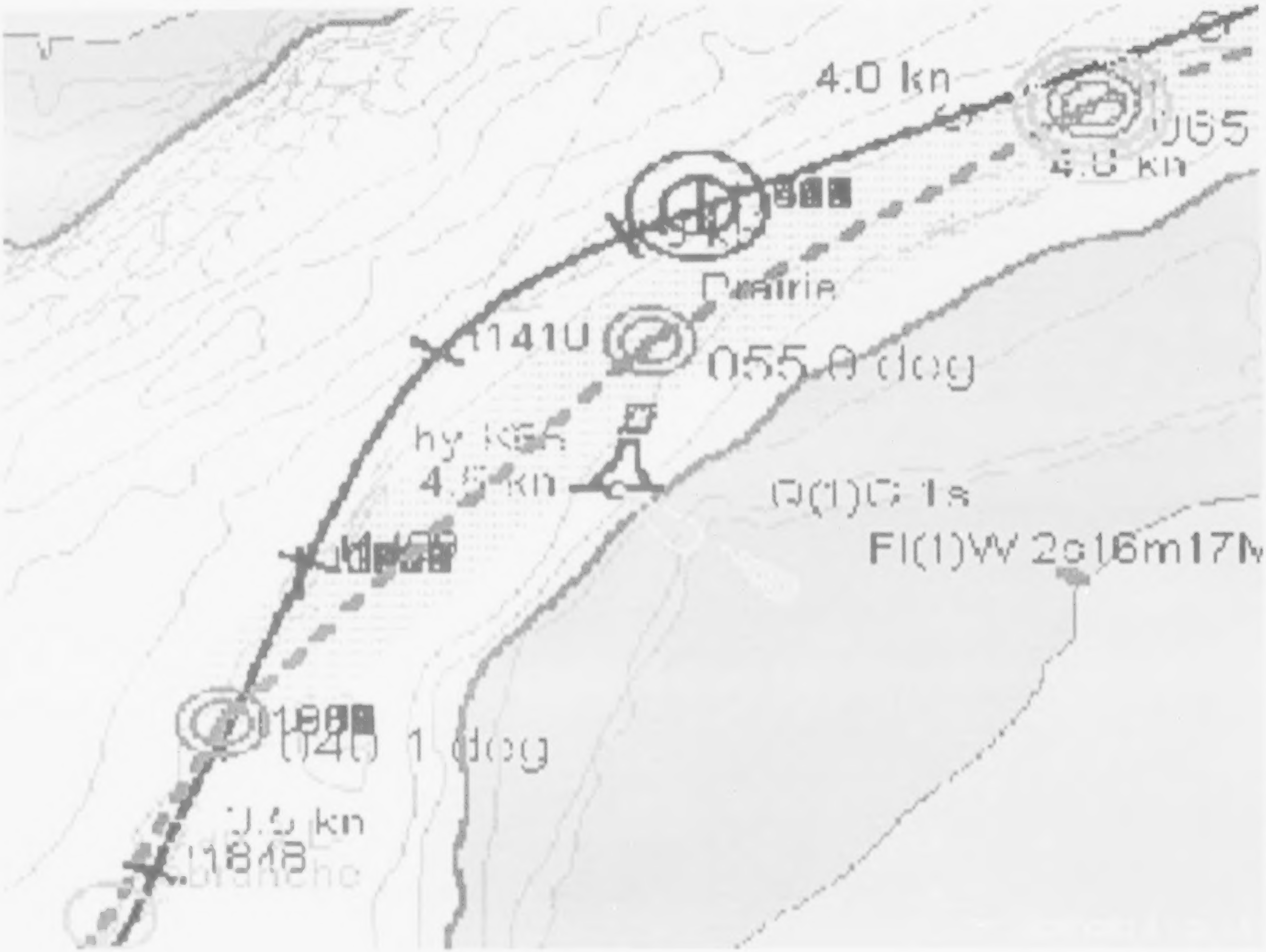

4:VLCC
Ownship-1
11:Exale


4.0 kn
065
4.0 kn
3.5 kn
Prairie
055.0 deg
by kas
4.5 kn
Q(1)G 1s
Fl(1)W 2s16m17M
Helm order
980
040.1 deg

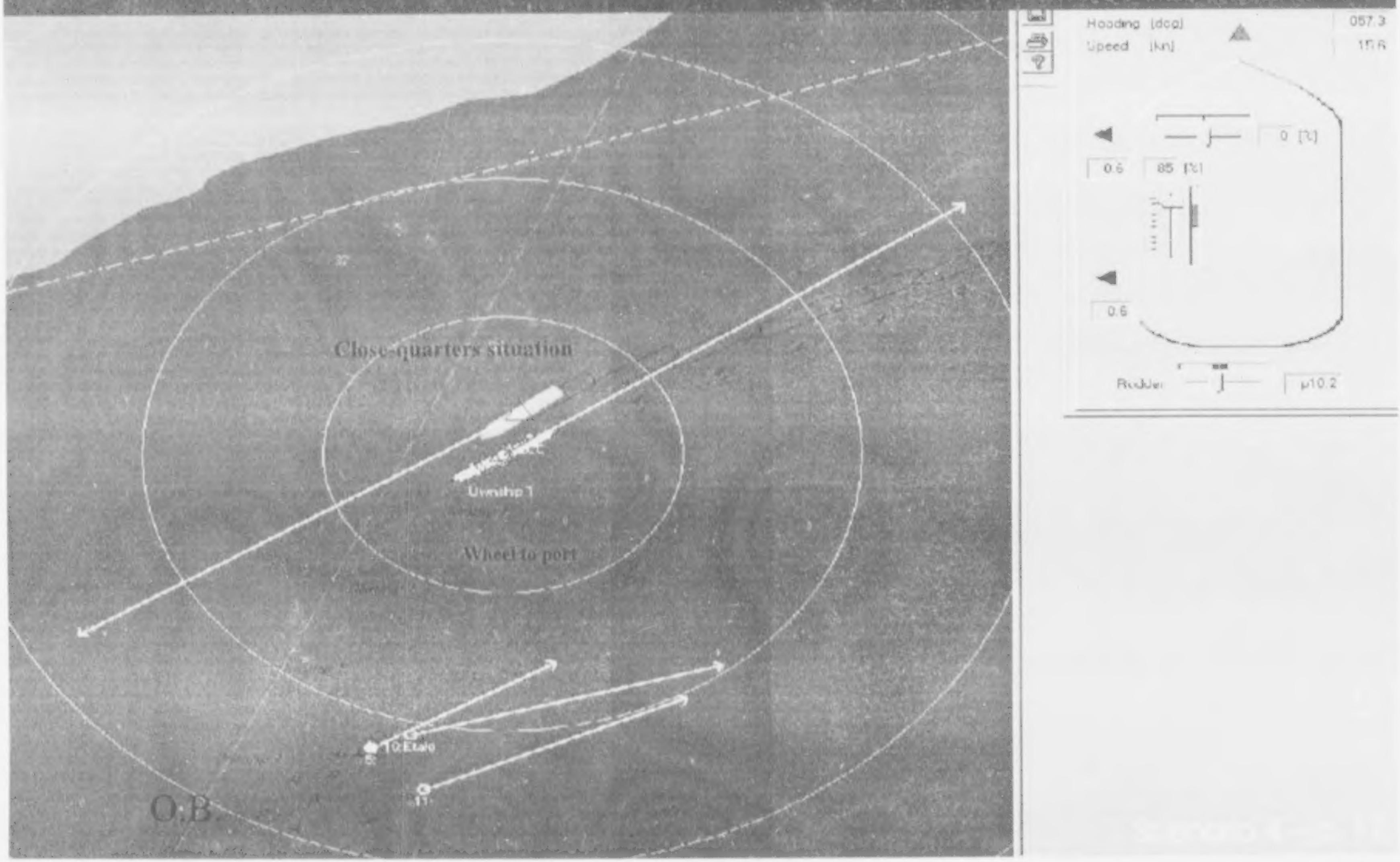
- The helmsman turns the wheel to starboard 10°, a normal angle for this type of ship unless circumstances dictate otherwise
- Fairly quickly the pilot sees that he is veering to the north, and he orders 070°
- Seeing the lights of the VLCC in the rain near the bow, he orders that the wheel be kept to starboard
- The least serious consequence in such a situation would be passing rather close
- The reason the ship veers to the north is straightforward
  - Change of course a bit late
  - Ebb tide current pushing ship north
  - SSW wind increasingly abeam
  - Normal effect of sideways drift during course alteration



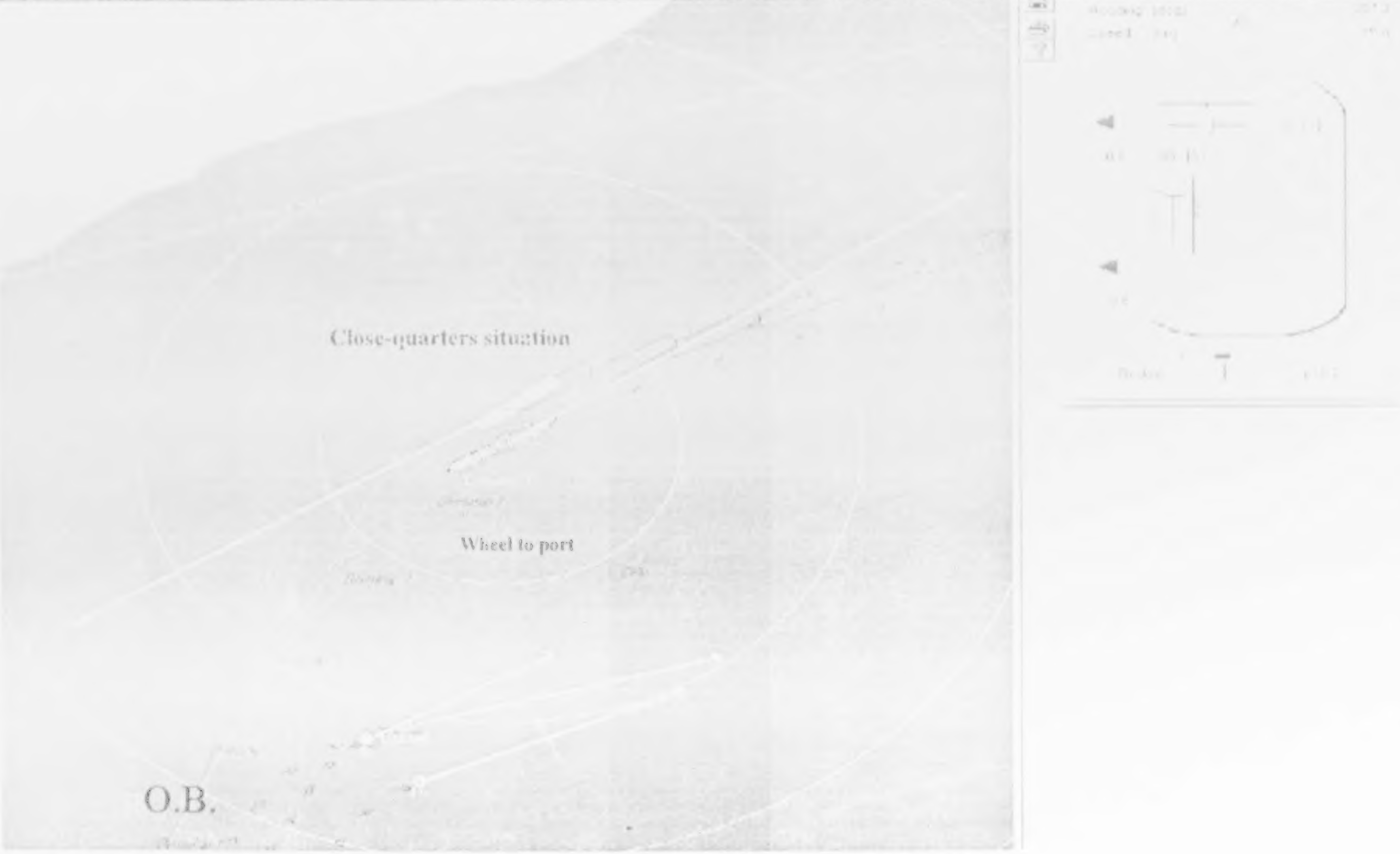
Passing closer then planned
(i.e., relatively close)


4.0 kn
065
4.0 kn
Prairie
1410
055.0 deg
hy K6A
4.5 kn
Q(1)G 1s
Fl(1)W 2s16m17M
040.1 deg
0.5 kn
1848
Blanche

- If the pilot had waited a few seconds more before turning …



# • If the pilot had waited a few seconds more before turning ...



- Can a VLCC in this type of situation (SSW wind, ebb tide current taking the ship strongly northward) move north without risk?
- The turning rate of this type of ship is about 30 degrees/minute and achieving this rate takes some time (slowing not an option)
- A change to starboard then back to port is unthinkable (danger of exposing left flank and danger of grounding)
- The downbound ship is doing about 18 knots through water (23 over ground); little reaction time for upbound ship

## There are ways of minimizing the risks associated with this type of situation

- Having a second pilot is one
- When the vessel has a big crew, good resource management is another way of reducing risk
- For example, have an extra officer on watch on the bridge whose sole task is to monitor manoeuvres
- His sole task would be to ensure that the manoeuvres are appropriate. But would this second officer have the local knowledge necessary to react in time?
- Are there enough officers for this sort of work? Are the officers sufficiently rested?

# Could an ECDIS take the place of a second pilot?

- An ECDIS is a system that displays electronic navigation charts in S-57 format on a screen of regulation size

- Using an ECDIS instead of paper charts, and in compliance with all IMO operating standards, calls for ongoing monitoring by a qualified person when in confined waters or pilotage waters

# Let's go over the events again, analyse the chain of errors and propose mitigation measures

It's hard to determine exactly where a pleasure craft, especially a sailboat, will be located at a particular time. Here are the errors that initiated the chain of events:

- Visibility was 5-7 miles, less during showers: this should be interpreted as less than 5 miles rather than 5 miles
  - Mitigation: further reduce speed
- The ship's speed over ground was perhaps overestimated, suggesting that the sailboats would be overtaken earlier than they were (or the speed of the sailboats was underestimated)
  - Mitigation: use GPS or ECDIS technology to determine the speed over ground; the officer could have used ARPA to see the time and place of the CPA

- The ship had passed its course alteration point when it started to turn
  - Mitigation: use radar ranges (before course alteration point) if visual landmarks are not available because of reduced visibility
  - Use ECDIS, which is an excellent way of confirming position
- If pilot fatigue was a factor in the scenario:
  - Would it possible to have intermediate pilot embarcation stations to reduce the transit time from station to station?
  - This could reduce the risk of error due to pilot fatigue

If pilot fatigue was a factor in the scenario:

- We have already suggested a second officer on the bridge
- Does this second officer have the local knowledge needed to react on time?
- Are there enough officers to do this kind of work?
- Are the officers sufficiently rested?
- Is this solution economical?

MARITIME INNOVATION

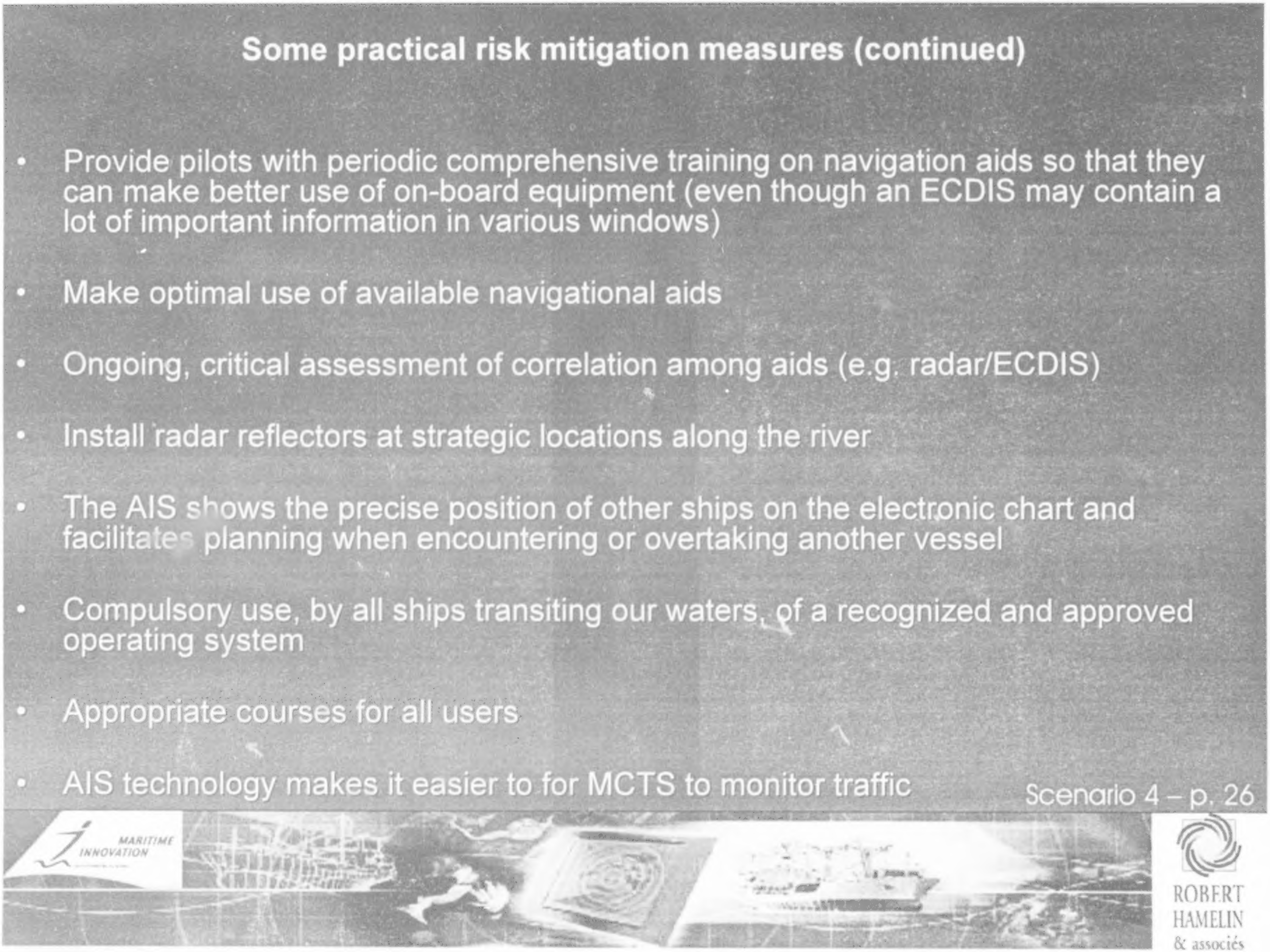
ROBERT HAMELIN & associés

Here are some things that can create a risky situation:

- Surveys containing unclarified contradictions
- Disagreement between people of equal weight in the navigation process
- Subordinate's opinion not taken into consideration
- Failure to comply with elementary rules in tracking progress
- Inattention (fatigue?) and communication problems
- Small crew
- Lack of precise instructions on each person's tasks and lack of knowledge of routine duties
- Inadequate preparation and inadequate organization
- Overconfidence (in oneself or in electronic instruments)
- Under-utilization of available navigational aids
- Lack of supervision
- Misunderstanding of ship's manoeuvring characteristics
- Personnel under-used or misused, etc.

## Some practical risk mitigation measures

- Compulsory Bridge Resource Management course for all officers and pilots, with a focus on pilot/crew relations
- Periodic case studies of accidents, led by a professional (in addition to BRM courses)
- If possible, double the watch on the bridge in pilotage areas, with one officer assigned specifically to support the pilot
- Increase crew size so as to be able to double the watch
- Embark with two experienced helmsmen. Rotterdam is an example of this practice, though only one helmsman embarks with the pilot
- Assign a second pilot to assist the first one
- Provide officers with comprehensive training on electronic navigation aids, over and above the regular courses already given at naval colleges



## Some practical risk mitigation measures (continued)

- Provide pilots with periodic comprehensive training on navigation aids so that they can make better use of on-board equipment (even though an ECDIS may contain a lot of important information in various windows)
- Make optimal use of available navigational aids
- Ongoing, critical assessment of correlation among aids (e.g. radar/ECDIS)
- Install radar reflectors at strategic locations along the river
- The AIS shows the precise position of other ships on the electronic chart and facilitates planning when encountering or overtaking another vessel
- Compulsory use, by all ships transiting our waters, of a recognized and approved operating system
- Appropriate courses for all users
- AIS technology makes it easier to for MCTS to monitor traffic

# Scenario 5

# Docking at Le Foulon

# Human Error and Possible Consequences in Confined Waters

## Scenario 5

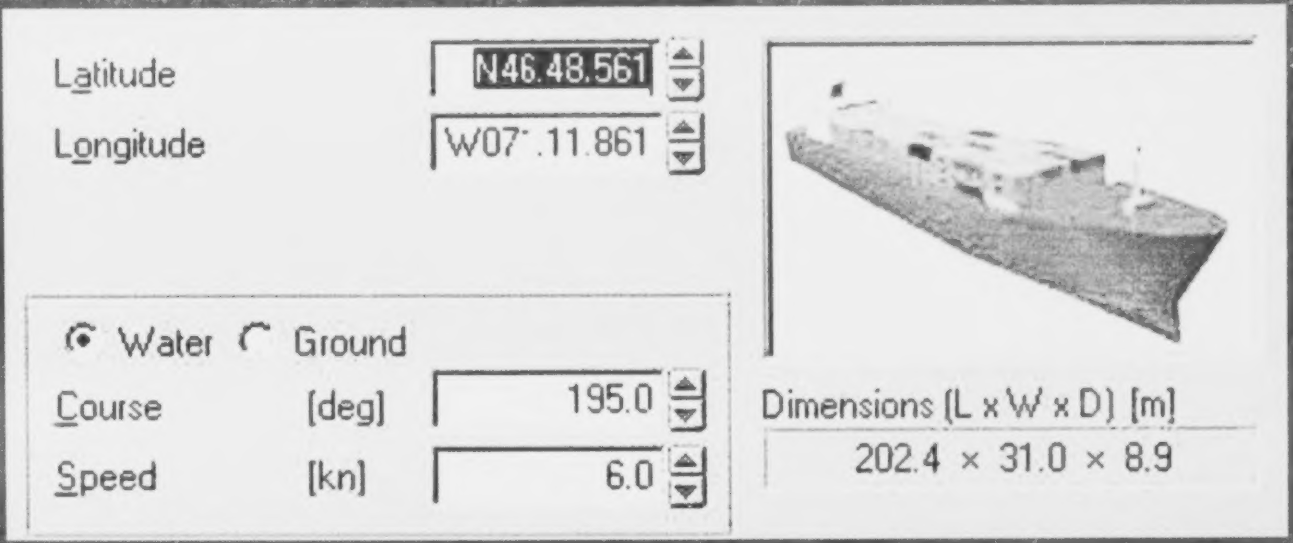
## Docking at Le Foulon

MARITIME INNOVATION

ROBERT HAMELIN & associés

## Carrier: Container ship

- Loaded 203 m ship
- Beam: 31 m
- Displacement: 32,930 cubic metres
- Draft forward: 8.6 m
- Draft aft: 9 m
- Max. forward speed: 25 knots
- Max. reverse speed: 9.8 knots
- Engine: 46,820 kW



Latitude: N46.48.561

Longitude: W07°.11.861

● Water ○ Ground

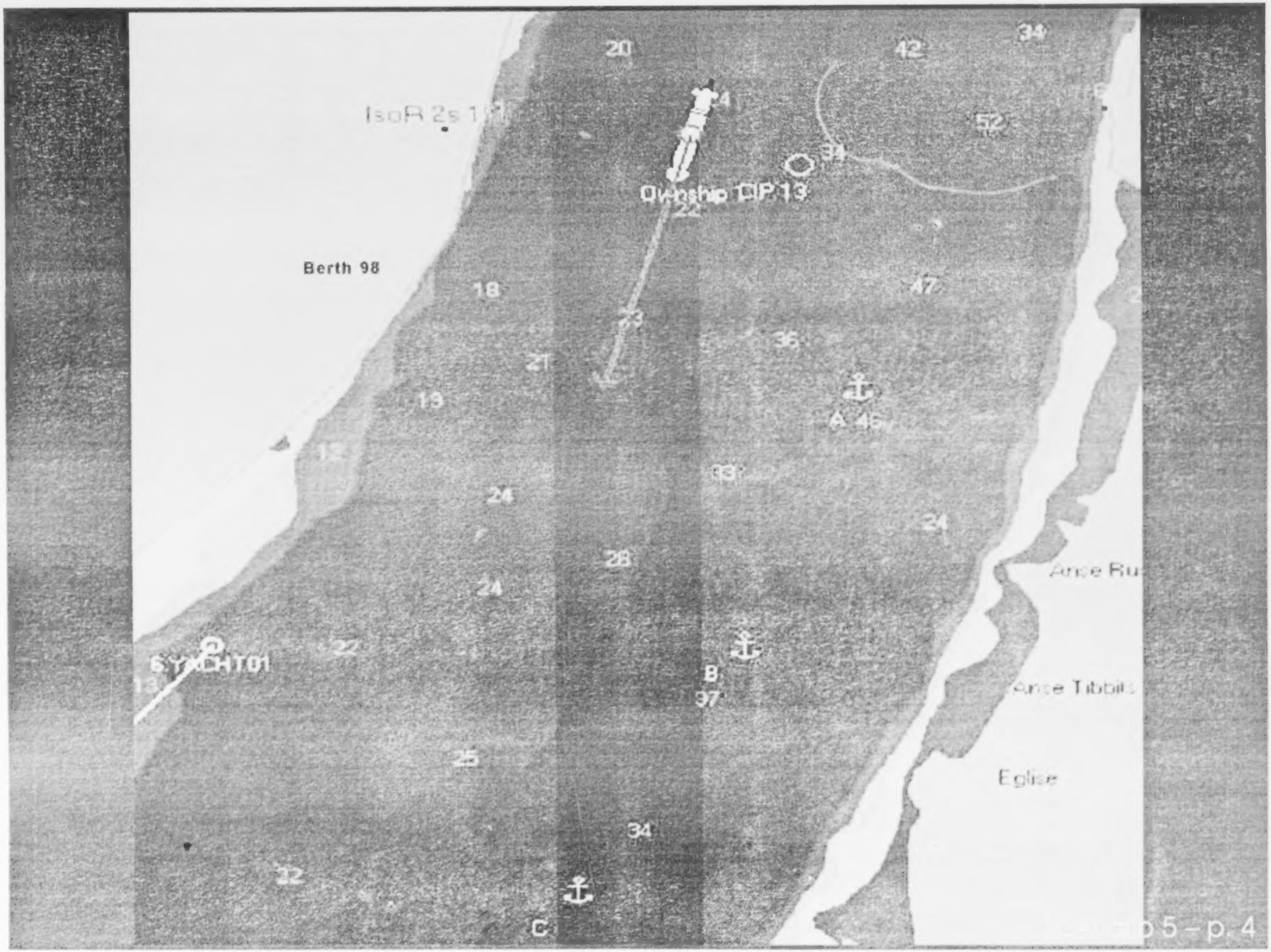
Course [deg]: 195.0

Speed [kn]: 6.0

Dimensions (L x W x D) [m]: 202.4 × 31.0 × 8.9

# Hypothetical situation

- Ship at calling point 13
- Speed through water 6 knots
- Visibility average, light NE wind
- Slack tide, negligible current
- Destination: berth 105/106
- A 150 m vessel is anchored at berth 102
- A small oil tanker is anchored at berth 108
- Two oil tankers are anchored at Ultramar


20
42
34
IsoR 2s 1
24
52
34
Ownship CIP 13
22
Berth 98
18
47
23
36
21
19
A 46
13
33
24
24
28
24
Anse Ru
22
YACHT01
B
37
Anse Tibbits
25
Eglise
34
32
C
5 – p. 4

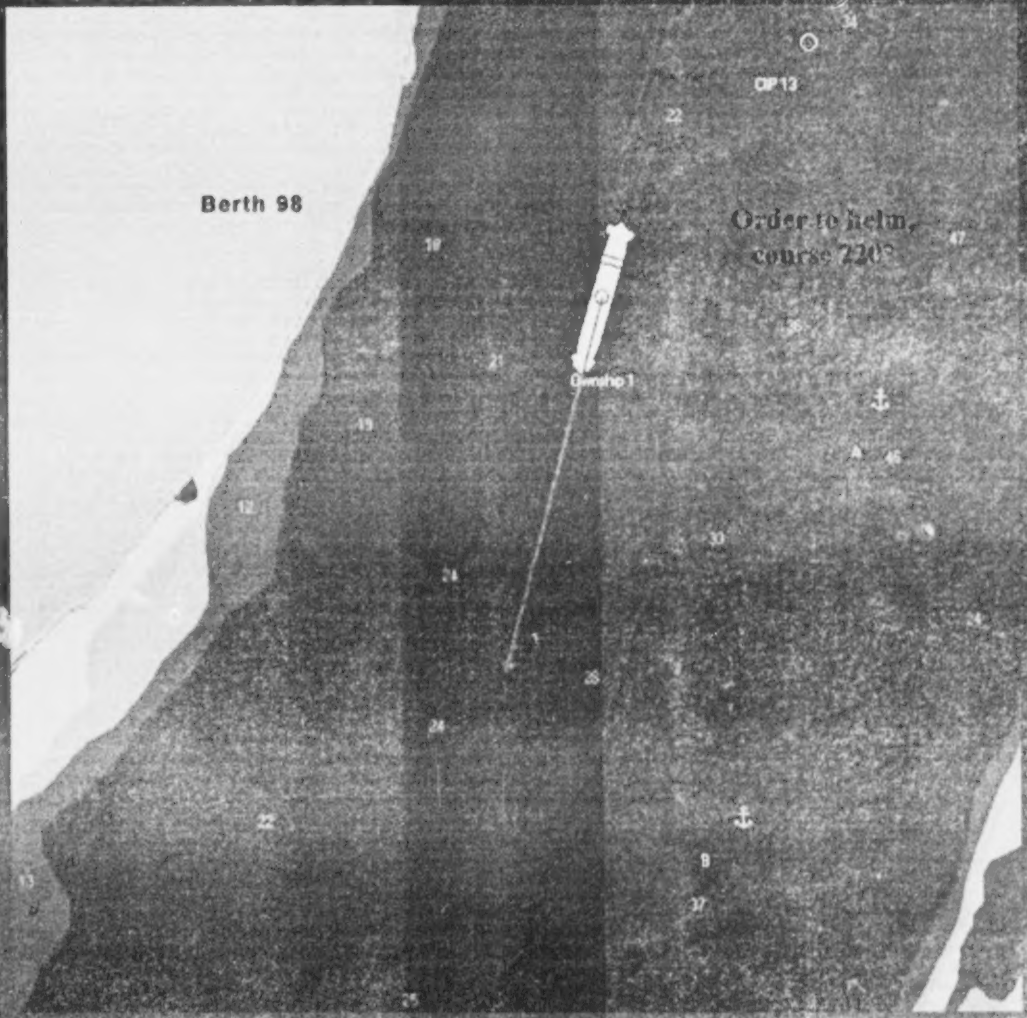
- The master assumes the responsibility of not using tugs

- The pilot explains the manoeuvre he intends to use for the docking: keep a good distance from the ship anchored at berth 102, arrive with an approach angle of about 30°, accelerate to start turning starboard, then reverse, then complete with the assistance of the hawsers and the bow thruster if necessary

- The master agrees

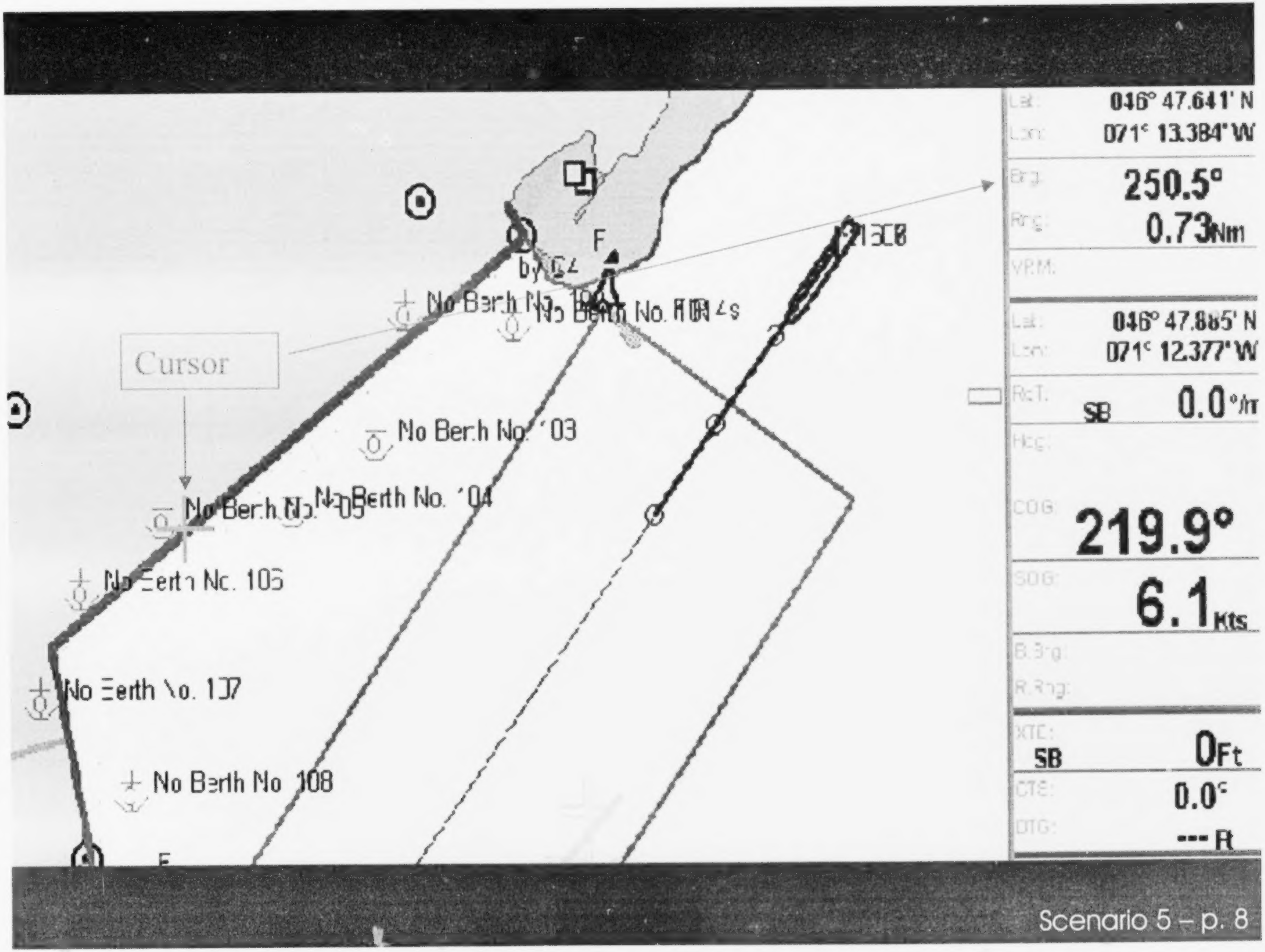
- It is also agreed that a helm order will always be 10° unless otherwise stated (large effective rudder)

- Off berth 98, the pilot orders 220°
- The master passes the order to the helmsman, who speaks neither English nor French

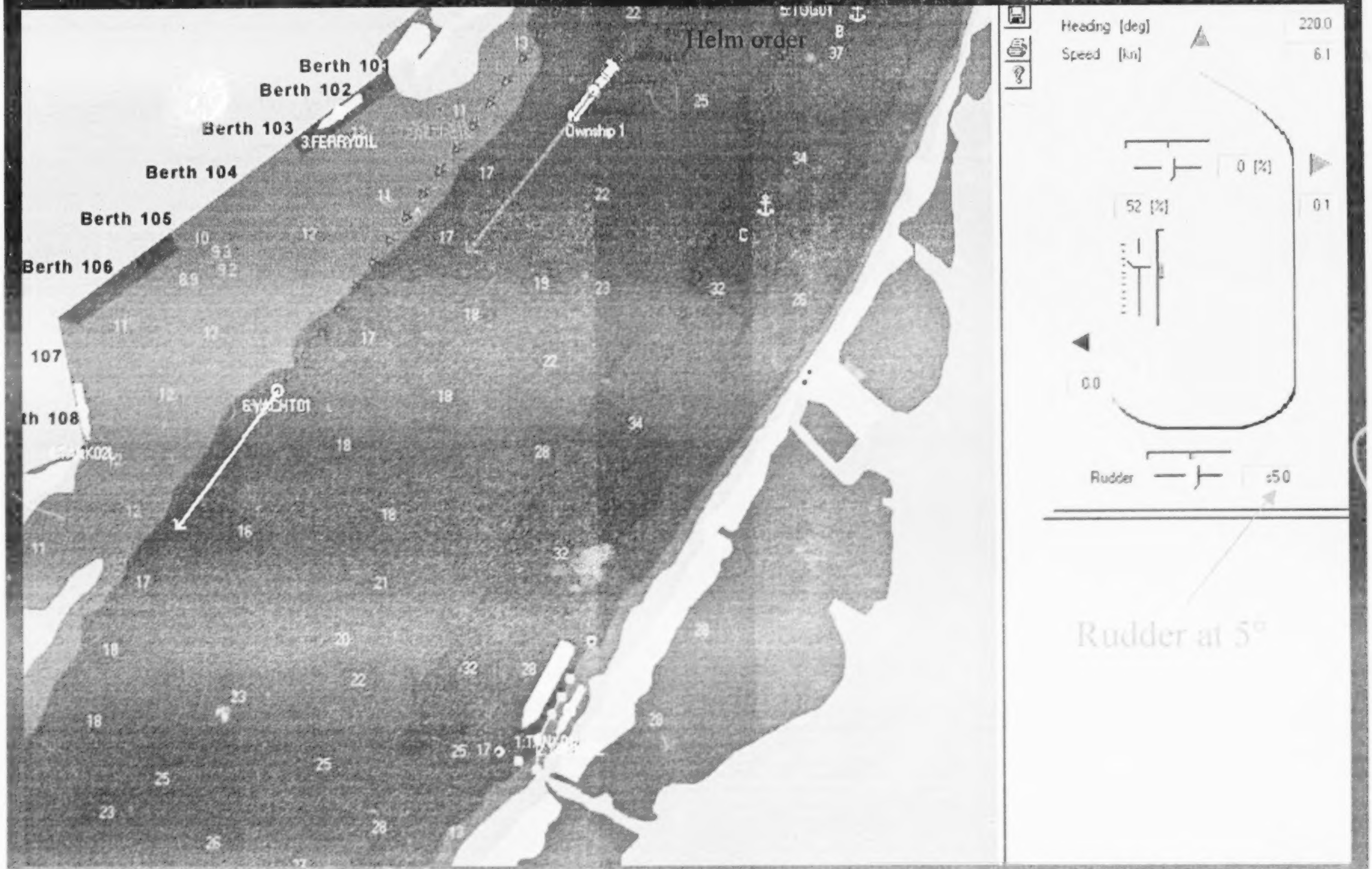


- Off berth 98, the pilot orders 220°
- The master passes the order to the helmsman, who speaks neither English nor French

- With Q4 forward of the beam, pilot orders 260°
- The master has placed the e-chart cursor on the destination berth and sees 250°
- He transmits the pilot's order but tells the helmsman to turn the wheel 5° (instead of the standard 10° )
- The ship turns too slowly and soon the pilot asks for a greater angle
- The master asks the helmsman for 5° more and increases the RPMs in order to turn more quickly; seeing his error, he orders hard to starboard
- *The pilot gives a helm order or engine order that is not executed by the master (or, more rarely, by the watch officer) and the pilot is not informed*



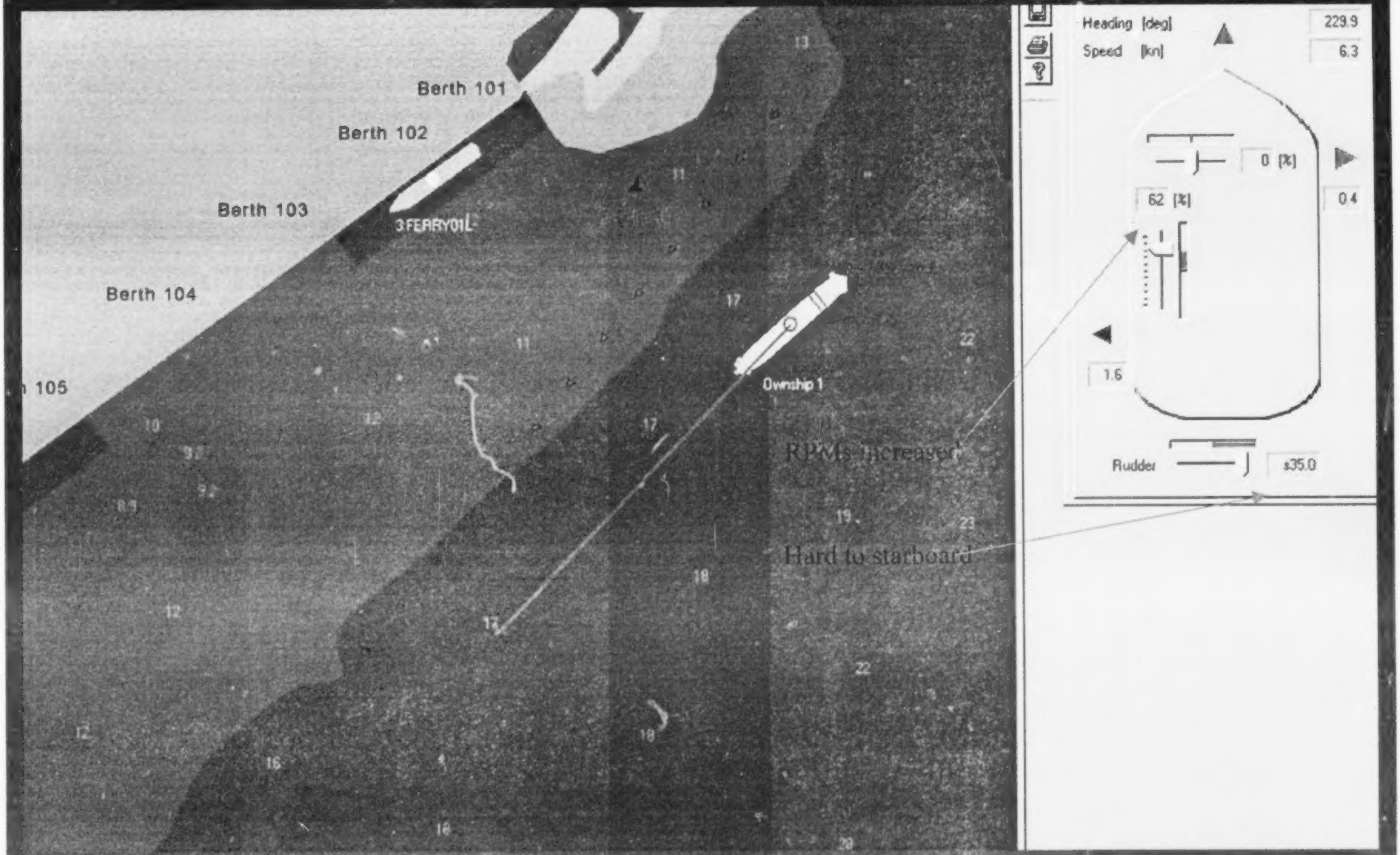
Lat: 046° 47.641' N
Lon: 071° 13.384' W
Brg: 250.5°
Rng: 0.73Nm
VRM:
Lat: 046° 47.885' N
Lon: 071° 12.377' W
RoT: SB 0.0°/m
Hdg:
COG: 219.9°
SOG: 6.1Kts
B.Brg:
R.Rng:
XTE: SB 0Ft
CTE: 0.0°
DTG: --- ft



Helm order

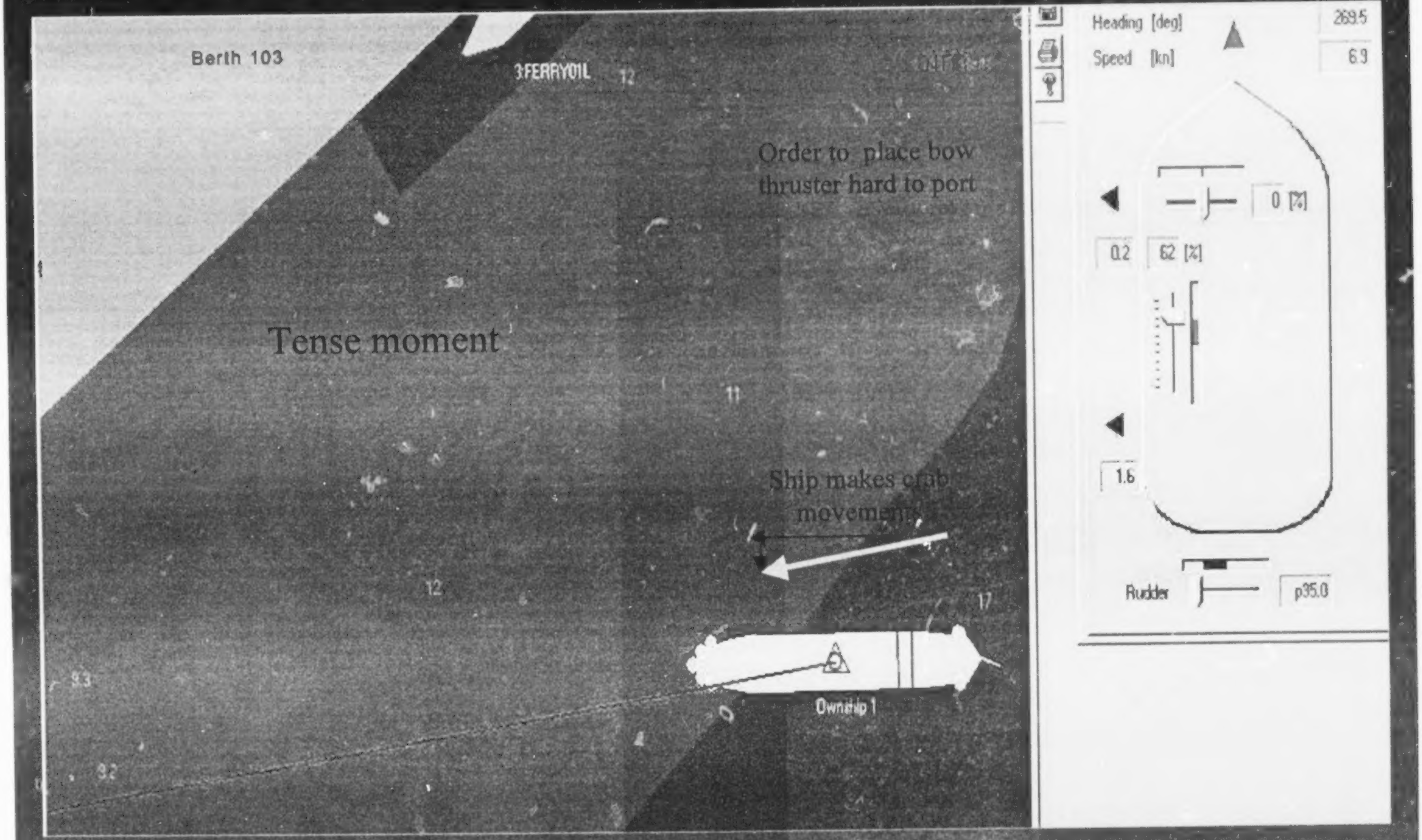
Rudder at 5°

- Why did the pilot order 260°?
- He knows that turning the the ship will bring him to the position he wants before the final approach
- Why did the master deliberately slow the turning?
- Because he was using a single source of information and was not visualizing the forward movement of the ship
- He did not ask the pilot for explanations
- Was it the master's fault?
- The pilot and master each bear part of the responsibility in this sort of situation



RPMs increased

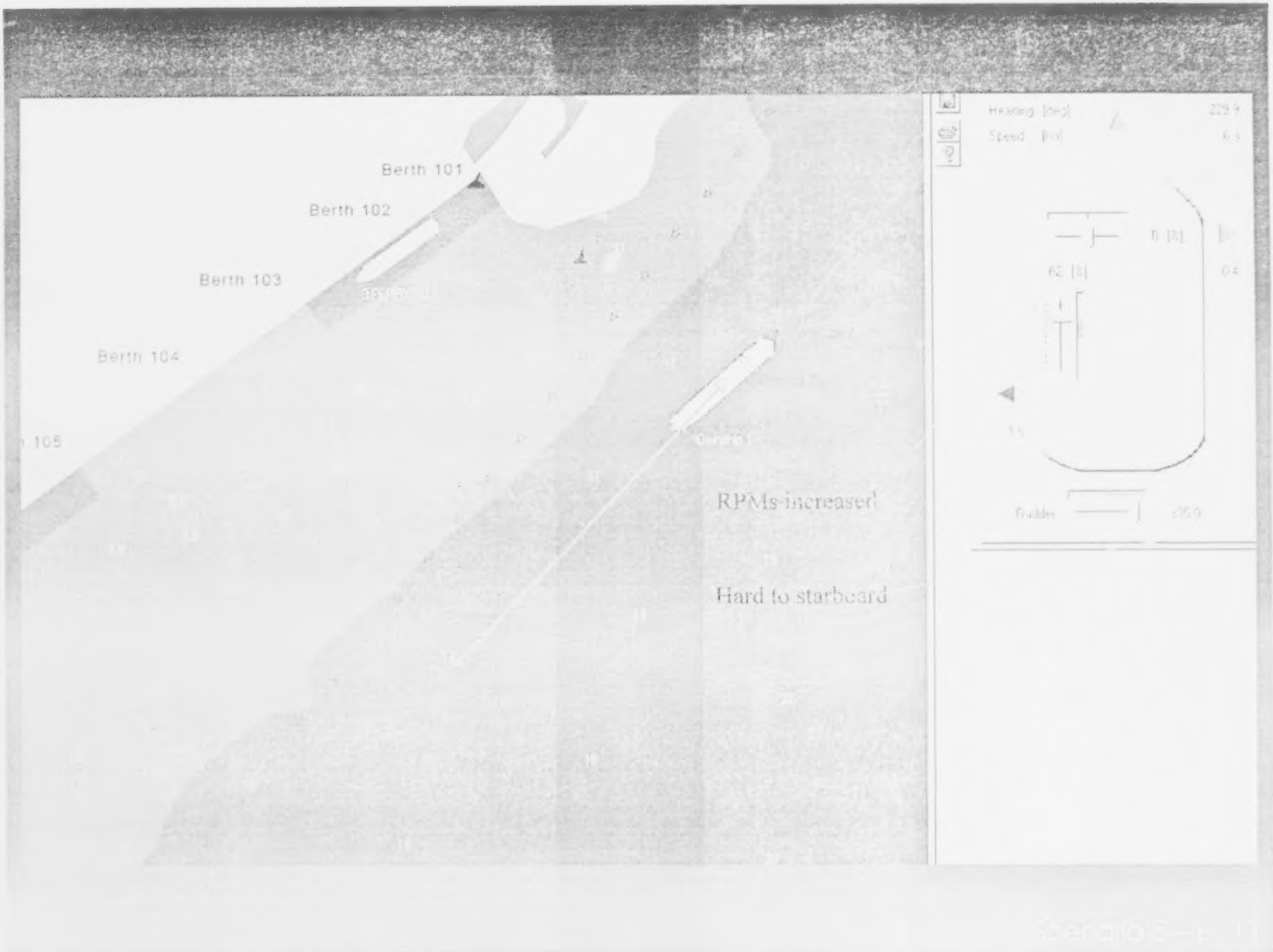
Hard to starboard



Tense moment

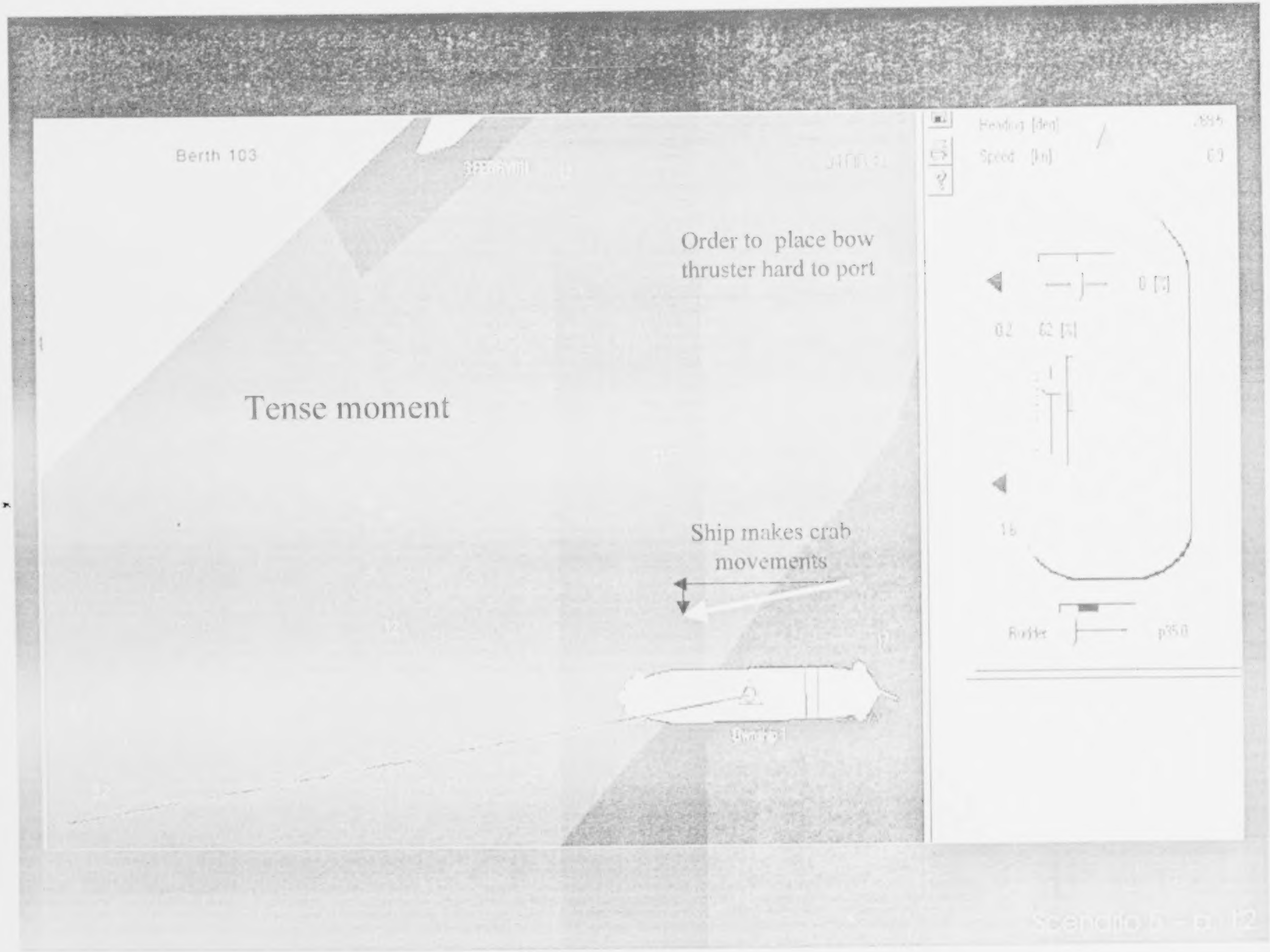
Order to place bow thruster hard to port

Ship makes crab movement



RPMs increased

Hard to starboard



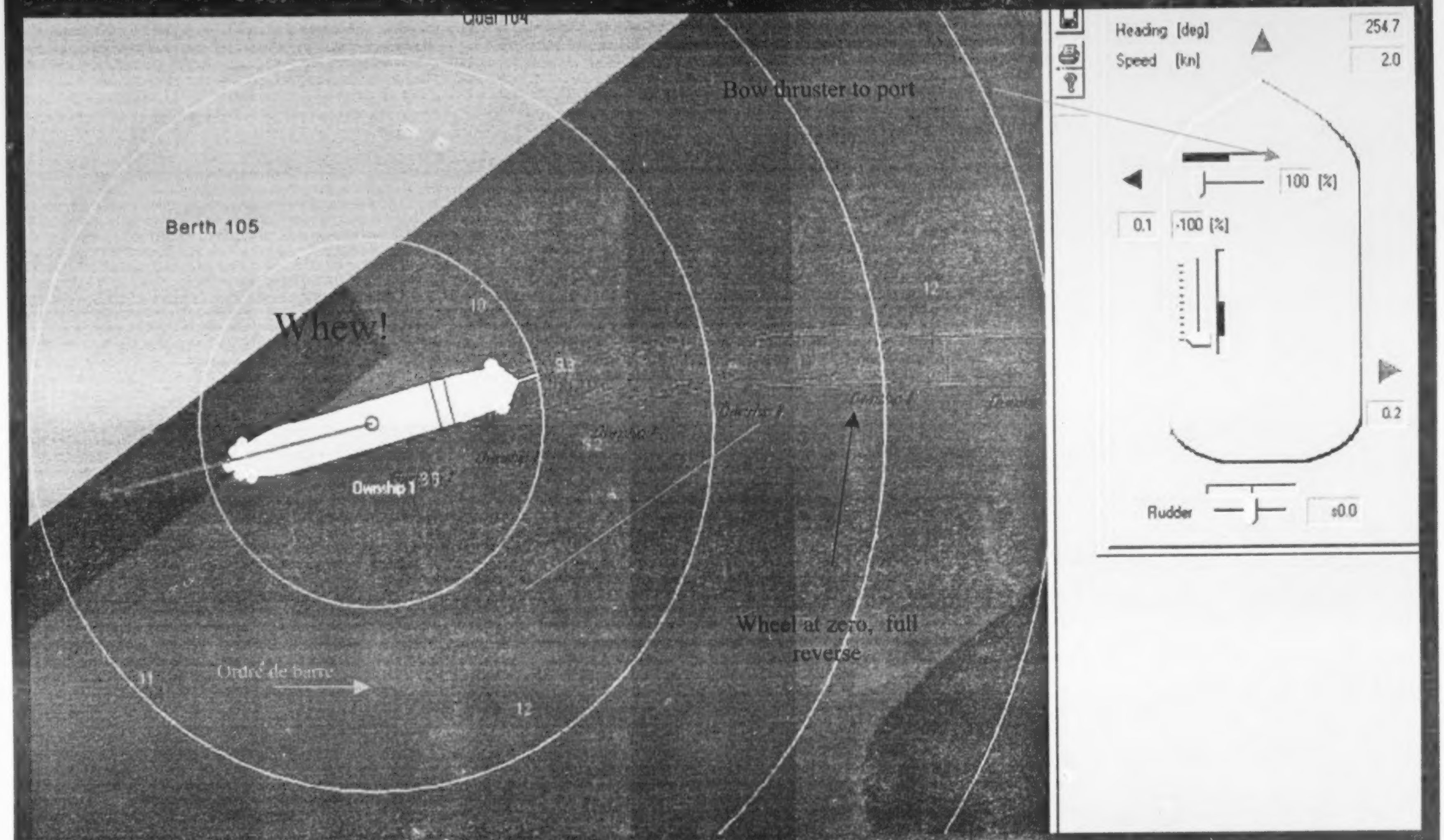
# Tense moment

Order to place bow thruster hard to port

Ship makes crab movements

A container ship gives a view of the environment that can be rather disconcerting because of:

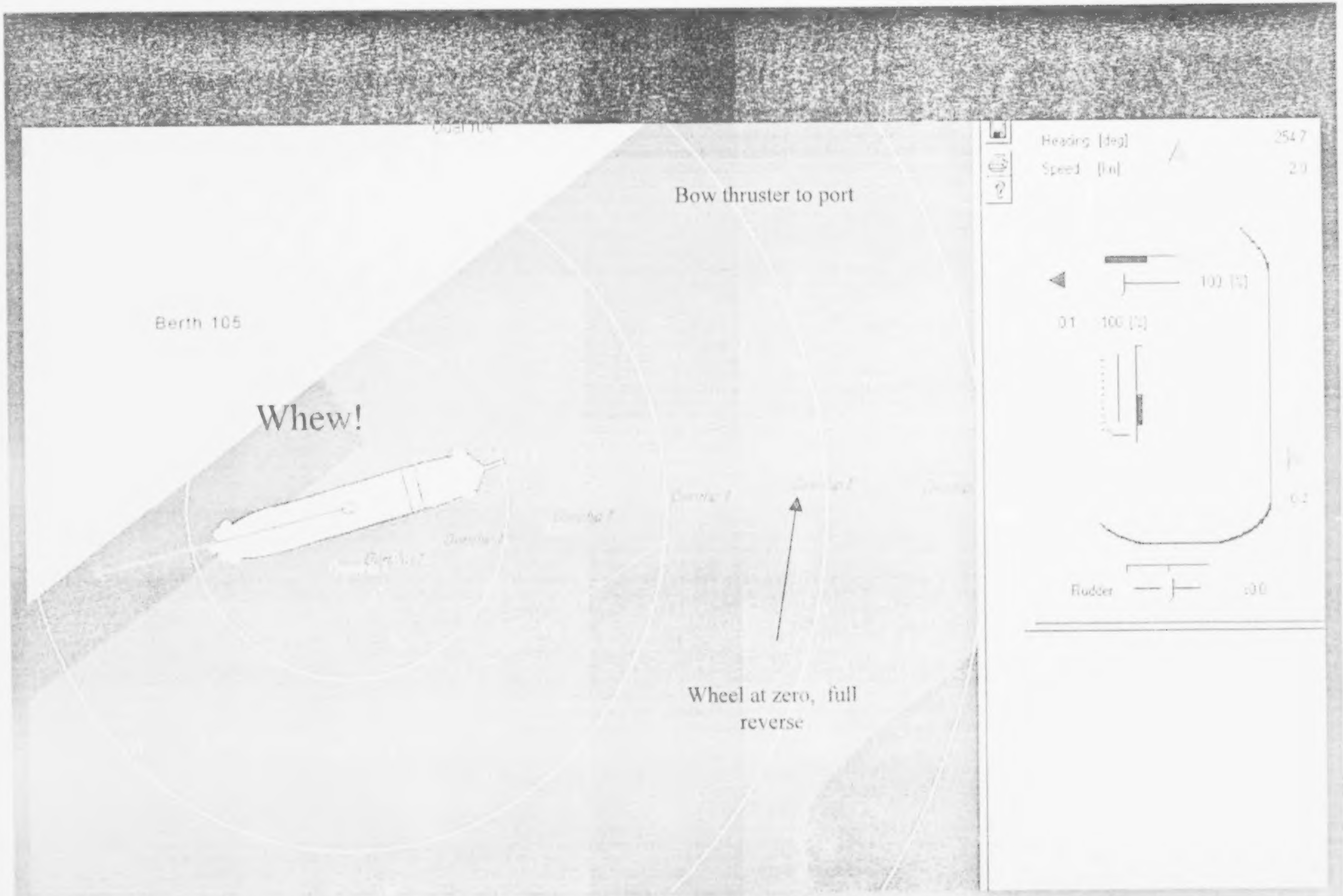
- The height of the eye
- The land moving past in a way that is distorted by the vessel's large dimensions
- The impression that the berth ahead is nearer than it actually is



Whew!

Bow thruster to port

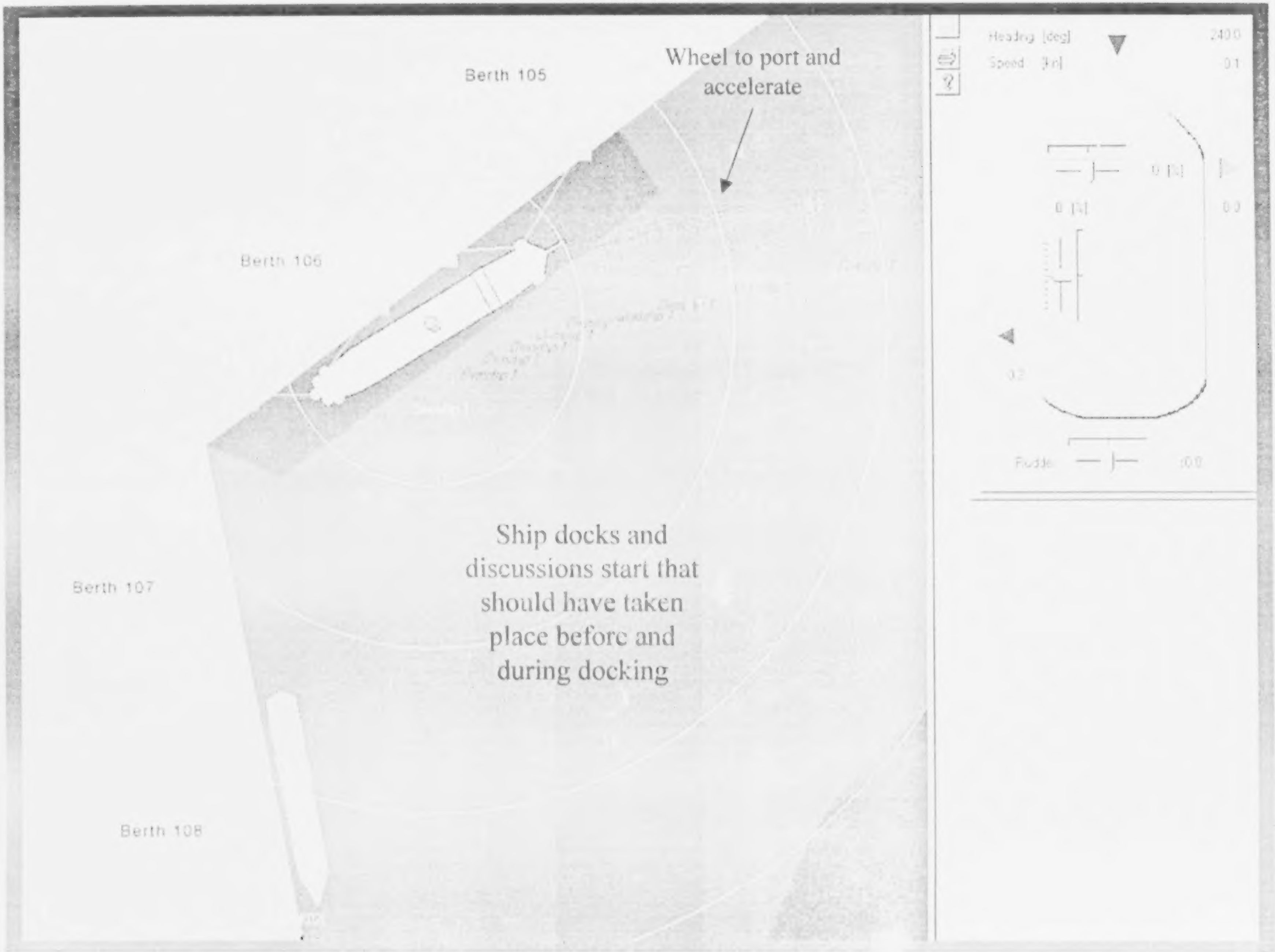
Wheel at zero, full reverse



Bow thruster to port

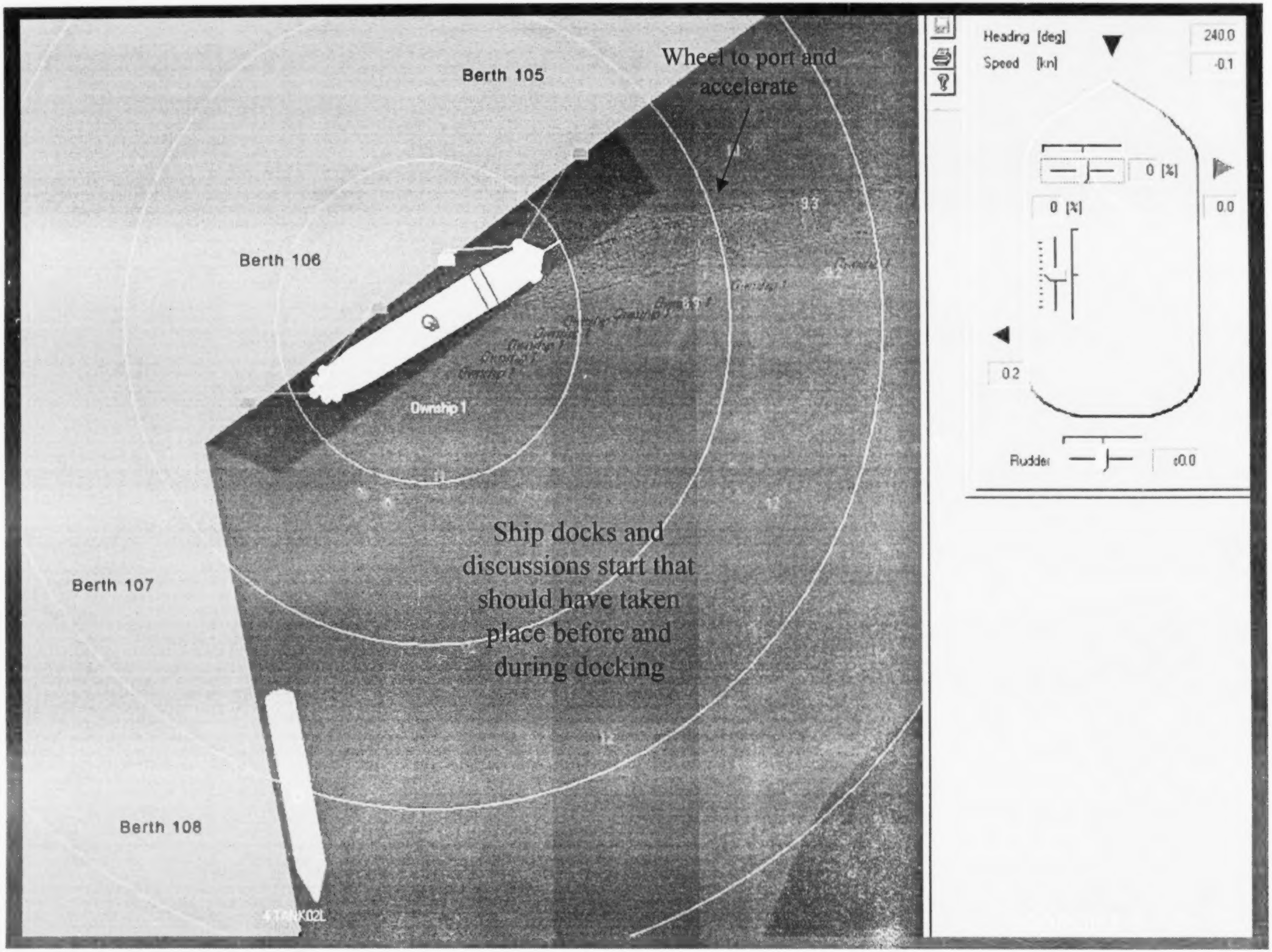
Whew!

Wheel at zero, full reverse



Wheel to port and accelerate

Ship docks and discussions start that should have taken place before and during docking



Wheel to port and accelerate

Ship docks and discussions start that should have taken place before and during docking

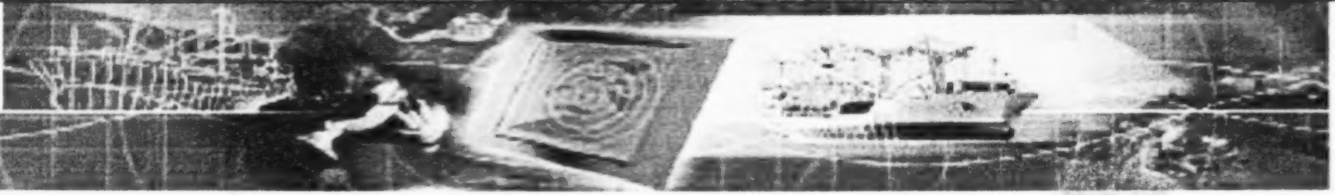
- Clearly there was no effective bridge resource management, so the responsibility is shared
- Yes, the master may know his ship, but still…!
- Since he always uses pilots for docking manoeuvres, he does not necessarily have the expertise to dock safely
- The pilot does not know the ship as well as the master but he does have experience in docking manoeuvres
- Clearly what we have here are complementary strengths which, unfortunately, were not properly used

## Preventive measures

- Comply with BRM procedures calling for exchange of information among all members of the crew.
- Pilot must always ensure that orders are executed correctly
- A simple glance at the helm indicator will tell the pilot what the situation is right away
- The master must say what he is doing, especially *if he is not executing* the pilot's recommendations
- The master must explain why he does not wish to execute the pilot's recommendations
- Have an officer track progress using the available technology
- ECDIS and radar can complement each other in this type of situation
- A well-trained officer could have sent an alarm signal before the situation deteriorated
- Master and pilot have experience that is complementary *if BRM principles are properly applied*

## There are ways of minimizing the risks associated with this type of situation

- Having a second pilot is one
- When the vessel has a big crew, good resource management is another way of reducing risk
- For example, have an extra officer on watch on the bridge whose sole task is to monitor manoeuvres
- But would this second officer have the local knowledge necessary to react in time?
- Are there enough officers for this sort of work?
- Are the officers sufficiently rested?
- Is such a practice economical?



# APPENDIX 6

## Manoeuvrability

# Manoeuvrability

## Estimating the weighting for manoeuvrability and ship size in risk evaluation

1- Objective

2- Limitation

3- Manoeuvrability coefficient

4- Size index

5- Results

6- Interpretation

7- References

## 1- Objective

The objective was to define a coefficient reflecting the ship's manoeuvrability independently of its size, so that ships of differing size can be compared. Since pilots operate in confined waters and ship size is an important element in evaluating risk, we then developed a size index correlating manoeuvrability and the ship's physical characteristics. Finally, we related the manoeuvrability coefficient and the size index so as to obtain a weighting that could be used for a specific ship in our risk assessment model.

## 2- Limitation

The sampling used to obtain the coefficients and factors was rather restricted. The data on just seven ships were used, though they may to a degree be representative of ships sailing the St. Lawrence River. For better results, the sampling would have to be representative of the actual traffic in the Lower St. Lawrence and Mid St. Lawrence Districts.

The seven ships were:

- a 140 m oil tanker
- a 300 m oil tanker
- a 170 m container ship
- a 294 m container ship
- a 200 m bulker
- a 190 m freighter
- a 170 m twin screw ro-ro

The technical specifications for these ships are available.

### 3- Manoeuvrability coefficient

The manoeuvrability of a ship will directly affect the risk of an incident during a transit. Our purpose was to quantify the increase in risk due to manoeuvrability. To make the estimate, we took three manoeuvrability-related criteria into account:

- crash stop (distance and time);
- turning circle (0-90 degrees) (advance and transfer);
- 20-degree zig zag test (overshoot and time).

These three criteria were given equal weighting. To obtain a coefficient that is independent of ship size, we weighted the coefficient's components by the size factor best correlated with manoeuvrability, namely length between perpendiculars (correlation coefficient: 0.958).

We used the following formula with each ship:

$$U = \frac{\left( \sqrt{\left( \left( \frac{Ac}{L} \right)^2 + \left( \frac{Tc}{L} \right)^2 \right)} + \sqrt{\left( \left( \frac{At}{L} \right)^2 + \left( \frac{Tt}{L} \right)^2 \right)} \right)}{2}$$

Ac = Advance crash stop
Tc = Transfer crash stop
At = Advance turning circle 90 deg.
Tt = Transfer turning circle 90 deg.
L = Length between perpendiculars
C = Overshoot – 20 deg. zig zag test
Tz = Execution time – 20 deg. zig zag test
Tc = Execution time - crash stop
N = Number of ships

The execution times and overshoots from the 20 deg. zig zag test may be obtained by simulation or by calculation.

Complete equation:

$$\mathrm{Im} = \frac{\left[\left(\dfrac{U}{\Sigma U/N}\right)+\left(\dfrac{Tz}{\Sigma Tz/N}\right)+\left(\dfrac{C}{\Sigma C/N}\right)\right]}{3}$$

The following results were obtained:

| | | |
|---|---|---|
| 140 m oil tanker | 1.00 | |
| 300 m oil tanker | 1.33 | |
| 170 m container ship | 0.92 | |
| 294 m container ship | 1.02 | |
| 200 m bulker | 1.05 | |
| 190 m freighter | 1.11 | |
| 170 m ro-ro | 0.58 | (twin screw) |

The weighting index is 1 when the ship's manoeuvrability is normal for its size in the sampling. If the index exceeds 1, the ship has low manoeuvrability; if it is less than 1, the ship has good manoeuvrability.

4- Size index

To obtain our size index, we used the ship's length and width because they are the factors best correlated with manoeuvring time. The following table shows the correlations based on the sample.

| Characteristic | Linear correlation |
|---|---|
| length BP | 0.9158 |
| width | 0.8207 |
| deadweight | 0.7281 |
| draft | 0.7882 |
| speed | 0.4331 |

The equation used to obtain the ship size index comes from statistical analyses based on simple and multiple regressions over the ship length, speed and reaction time.

$$D = (0.019287 * L) + (0.070488 * B) - 0.016266$$

* R2 = 0.90195

Complete equation:

$$Id = \left( \frac{D}{\sum D / N} \right)$$

The following results were obtained:

| | | |
|---|---|---|
| 140 m oil tanker | 23 | 0.7133 |
| 300 m oil tanker | 47 | 1.5322 |
| 170 m container ship | 28 | 0.8727 |
| 294 m container ship | 32 | 1.2790 |
| 294 m Canmar | 32 | 1.2790 |
| 200 m bulker | 32 | 1.0331 |
| 190 m freighter | 32 | 0.9775 |
| 170 m ro-ro | 26 | 0.8588 |

## 5- Results

Multiplying the manoeuvrability coefficient by the size factor, we obtain a weighting for the ship that reflects its size, speed and manoeuvrability:

| Ship | Size (*Id*) x Man. (*Im*) | Weighting |
|---|---|---|
| 140 m oil tanker | 0.7133 x 1 | 0.7142 |
| 300 m oil tanker | 1.5322 x 1.33 | 2.0423 |
| 170 m container | 0.8727 x 0.92 | 0.8046 |
| 294 m container | 1.2790 x 1.02 | 1.3035 |
| bulker | 1.0331 x 1.05 | 1.0826 |
| freighter | 0.9775 x 1.11 | 1.0894 |
| twin-screw ro-ro | 0.8588 x 0.581 | 0.4992 |

## 6- Interpretation

The higher the weighting, the greater the risk and thus the greater the additional effort required to deal with it.

| Effort required | Ship's weighting |
|---|---|
| low | 0.5 |
| medium | 0.75 |
| high | 1 |
| very high | 1.25 |
| borderline or impossible | 1.5 |

## 7- References

- *The effect of ship inherent controllability on piloted performance: Evaluation and prediction*. U.S. Coast Guard Research and Development Center and U.S. Department of Transportation.

- *Analysis of Kempf's standard maneuver test and proposed steering quality indices*. Nomoto K.

- *Ship Data Base Manager*. Kongsberg Norcontrol Simulation AS.

- *Description of ship model*. Kongsberg Norcontrol Simulation AS.

- *The effect of ship inherent controllability on piloted performance: The simulator experiment*. U.S. Coast Guard Research and Development Center and U.S. Department of Transportation.

- *Introduction to Econometrics*. G.S. Maddala, University of Florida.

# APPENDIX 7

## List of participants consulted

First round of consultations

Tuesday, November 11, 2003, at the office of the Lower St. Lawrence Pilots Corporation. Present:

Jacques Paquin, Innovation maritime
Alain Richard, Innovation maritime
Martin Fournier, Robert Hamelin & Associates
Guy Marmen, Corporation of Lower St. Lawrence Pilots
Jean Lapointe, Corporation of Lower St. Lawrence Pilots
Simon Pelletier, Corporation of Lower St. Lawrence Pilots
Michel Pouliot, Canadian Marine Pilots' Association
Gilles Giroux, Corporation of Mid St. Lawrence Pilots
Luc Drouin, Corporation of Mid St. Lawrence Pilots
Pierre Tremblay, Corporation of Mid St. Lawrence Pilots
Guy Bélanger, Corporation of Mid St. Lawrence Pilots
Nicolas Audet, Stratégie Saint-Laurent

Friday, November 20, 2003, at the office of the Shipping Federation of Canada. Present:

Jacques Paquin, Innovation maritime
Alain Richard, Innovation maritime
Martin Fournier, Robert Hamelin & Associates
Ivan Lantz, Shipping Federation of Canada
Anjuna Langevin, Shipping Federation of Canada
Jacques Luce, Maersk Sealand
Claude Gagné, Alcan
Donald Poirier, CP Ships
David Grieve, Fednav International
Réjean Lanteigne, Canadian Shipowners Association
Claude Dumais, St. Lawrence Ship Operators Association
Ross Baldwin, McLean Kennedy Inc.
Yoland Jodoin, Transport Desgagnés
Dan Karajeorge, Robin Maritime Inc.

Second round of consultations

Wednesday, February 18, 2004, in Quebec City in the Lafontaine Room, Auberge Ste-Foy. Present:

Alain Richard, Innovation maritime
Martin Fournier, Robert Hamelin & Associates
Guy Marmen, Corporation of Lower St. Lawrence Pilots
Jean Lapointe, Corporation of Lower St. Lawrence Pilots
Simon Pelletier, Corporation of Lower St. Lawrence Pilots
Michel Pouliot, Canadian Marine Pilots' Association
Gilles Giroux, Corporation of Mid St. Lawrence Pilots
Pierre Tremblay, Corporation of Mid St. Lawrence Pilots
Guy Bélanger, Corporation of Mid St. Lawrence Pilots

Tuesday, February 17, 2004, in Montreal at the office of the Shipping Federation of Canada. Present:

Alain Richard, Innovation maritime
Martin Fournier, Robert Hamelin & Associates
Ivan Lantz, Shipping Federation of Canada
Robert Dorais, Canadian Hydrographic Service
Nicole Trépanier, St. Lawrence Ship Operators Association
Claude Mailloux, SODES [St. Lawrence Economic Development Council]
Chad Allen, Orient Overseas Container Line
Claude Gagné, Alcan
Donald Poirier, CP Ships
David Grieve, Fednav International
Andrew Digby, Robert Reford, Bryan Wilson, Lower St. Lawrence Ocean Agencies

Third round of consultations

Thursday, March 25, 2004, in Quebec City in the Verdi Room of the Plaza Hotel. Present:

Jacques Paquin, Innovation maritime
Alain Richard, Innovation maritime
Martin Fournier, Robert Hamelin & Associates
Guy Marmen, Corporation of Lower St. Lawrence Pilots
Jean Lapointe, Corporation of Lower St. Lawrence Pilots
Simon Pelletier, Corporation of Lower St. Lawrence Pilots
Michel Pouliot, Canadian Marine Pilots' Association
Gilles Giroux, Corporation of Mid St. Lawrence Pilots
Pierre Tremblay, Corporation of Mid St. Lawrence Pilots
Guy Bélanger, Corporation of Mid St. Lawrence Pilots
Pierre Cloutier, Canadian Coast Guard (MCTS)

---

Friday, March 26, 2004, in Montreal at the office of the Shipping Federation of Canada. Present:

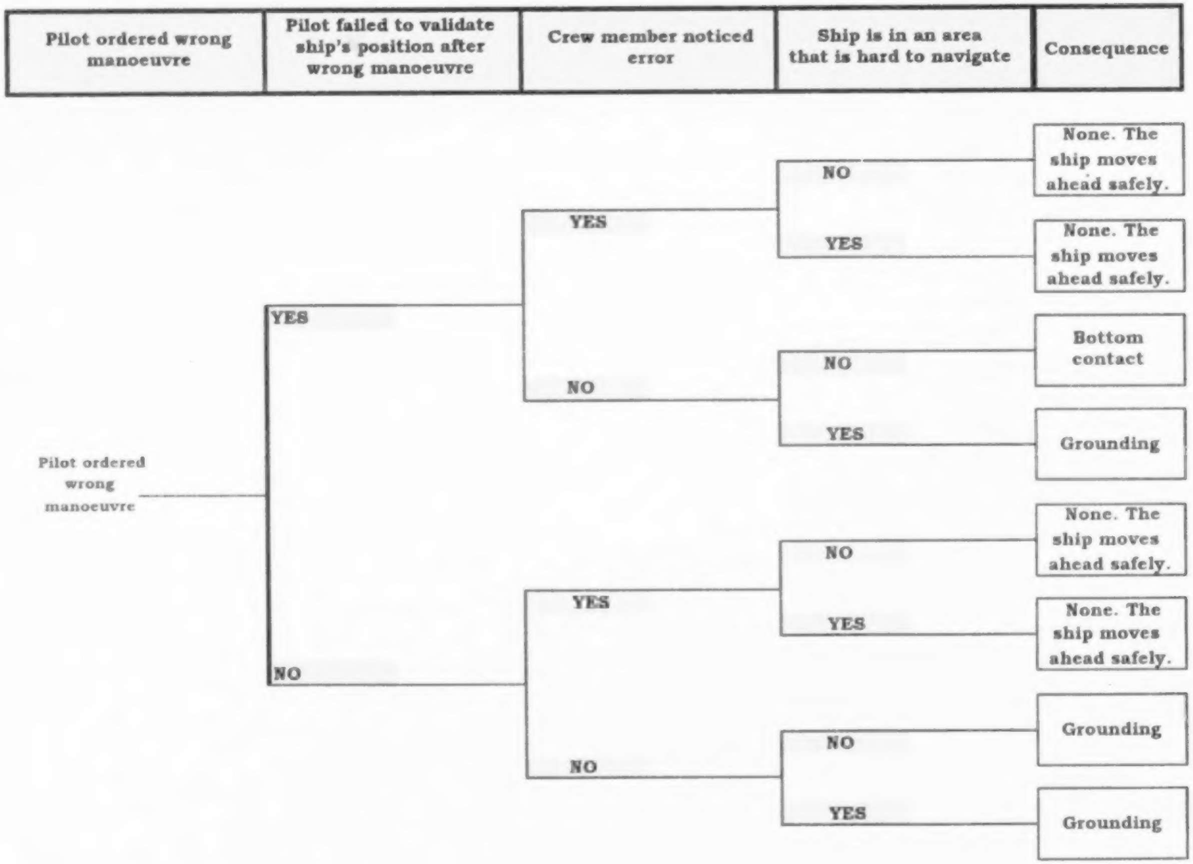
Jacques Paquin, Innovation maritime
Alain Richard, Innovation maritime
Martin Fournier, Robert Hamelin & Associates
Michael Broad, Shipping Federation of Canada
Ivan Lantz, Shipping Federation of Canada
Nicole Trépanier, St. Lawrence Ship Operators Association
Réjean Lanteigne, Canadian Shipowners Association
Chad Allen, Orient Overseas Container Line
Claude Gagné, Alcan
Donald Poirier, CP Ships
Denys Pouliot, Laurentian Pilotage Authority
Gilles Morin, Upper Lakes Group Inc. Trois-Rivières
Andrew Digby, Robert Reford, Bryan Wilson, Lower St. Lawrence Ocean Agencies

---

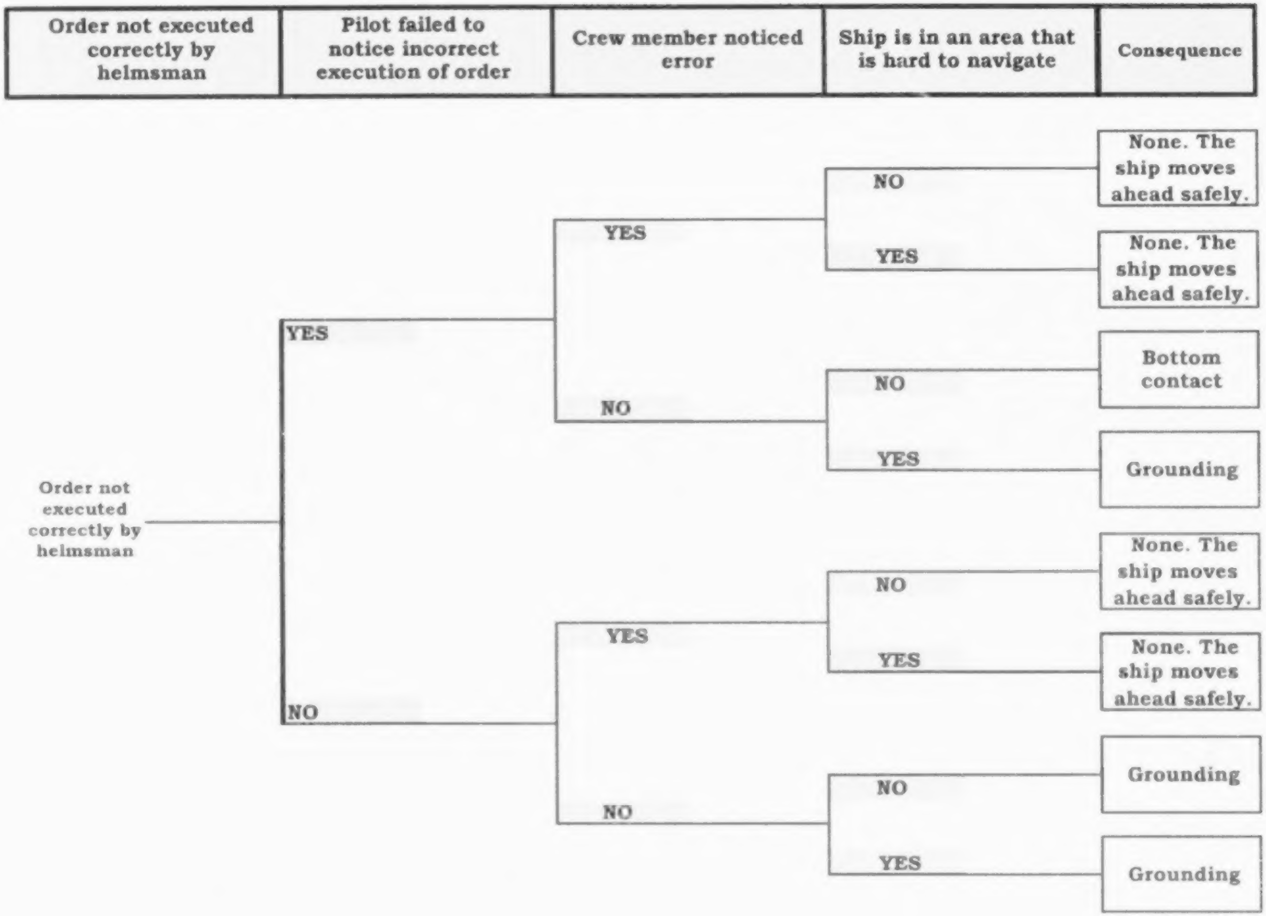
# APPENDIX 8

## Fault trees

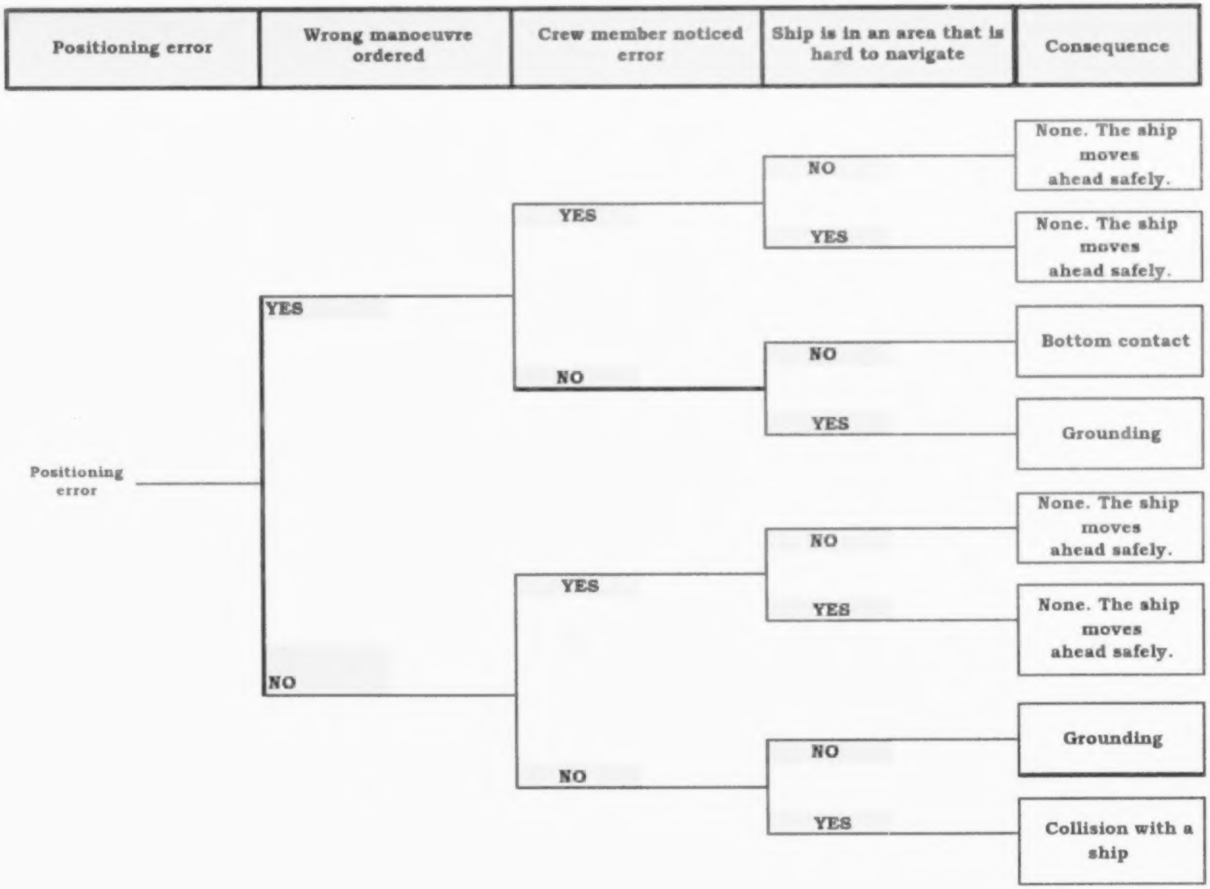
## *Pilot errs in preparing the navigation plan*


Pilot ordered wrong manoeuvre
Pilot failed to validate ship's position after wrong manoeuvre
Crew member noticed error
Ship is in an area that is hard to navigate
Consequence
Pilot ordered wrong manoeuvre
YES
NO
YES
NO
YES
NO
NO
YES
NO
YES
NO
YES
NO
YES
None. The ship moves ahead safely.
None. The ship moves ahead safely.
Bottom contact
Grounding
None. The ship moves ahead safely.
None. The ship moves ahead safely.
Grounding
Grounding

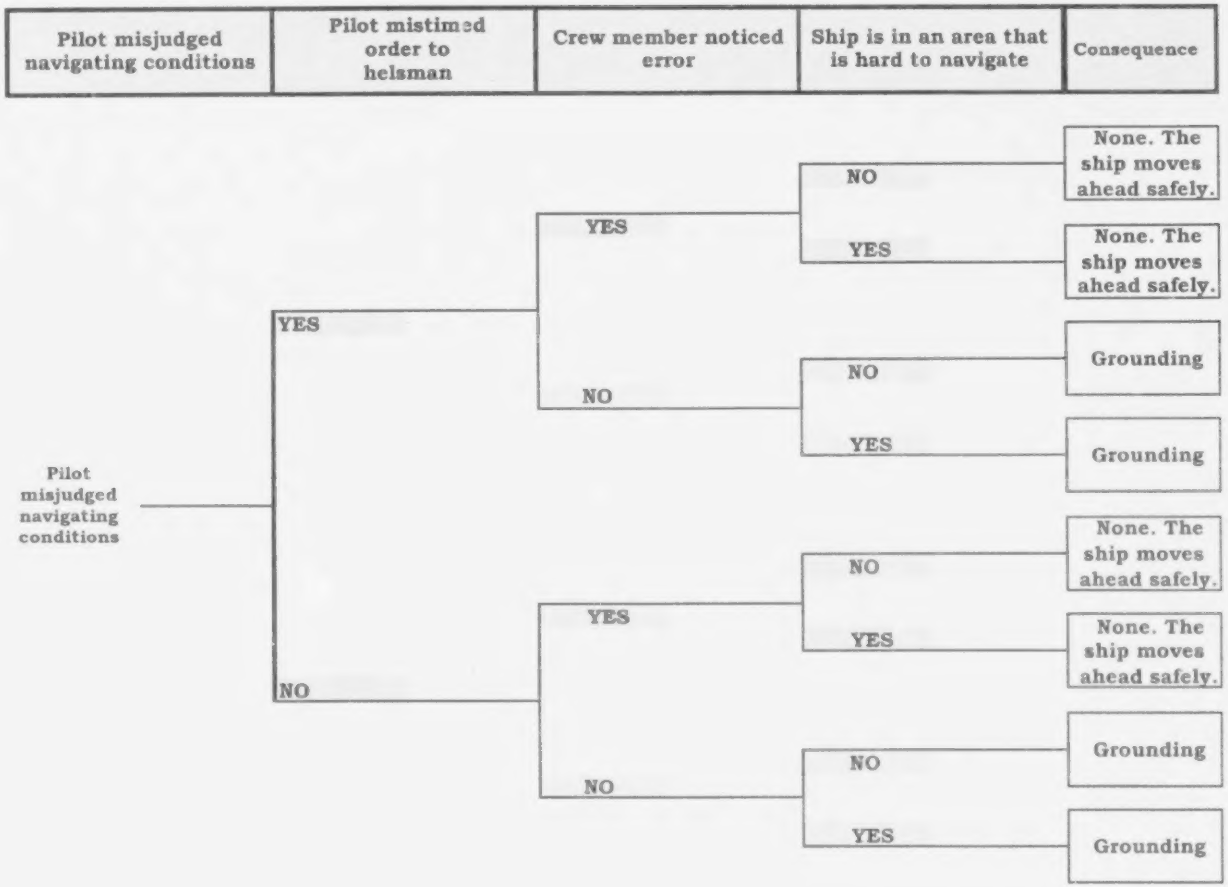
*Pilot errs in preparing the navigation plan*


Order not executed correctly by helmsman
Pilot failed to notice incorrect execution of order
Crew member noticed error
Ship is in an area that is hard to navigate
Consequence
Order not executed correctly by helmsman
YES
NO
YES
NO
YES
NO
NO
YES
NO
YES
NO
YES
NO
YES
None. The ship moves ahead safely.
None. The ship moves ahead safely.
Bottom contact
Grounding
None. The ship moves ahead safely.
None. The ship moves ahead safely.
Grounding
Grounding

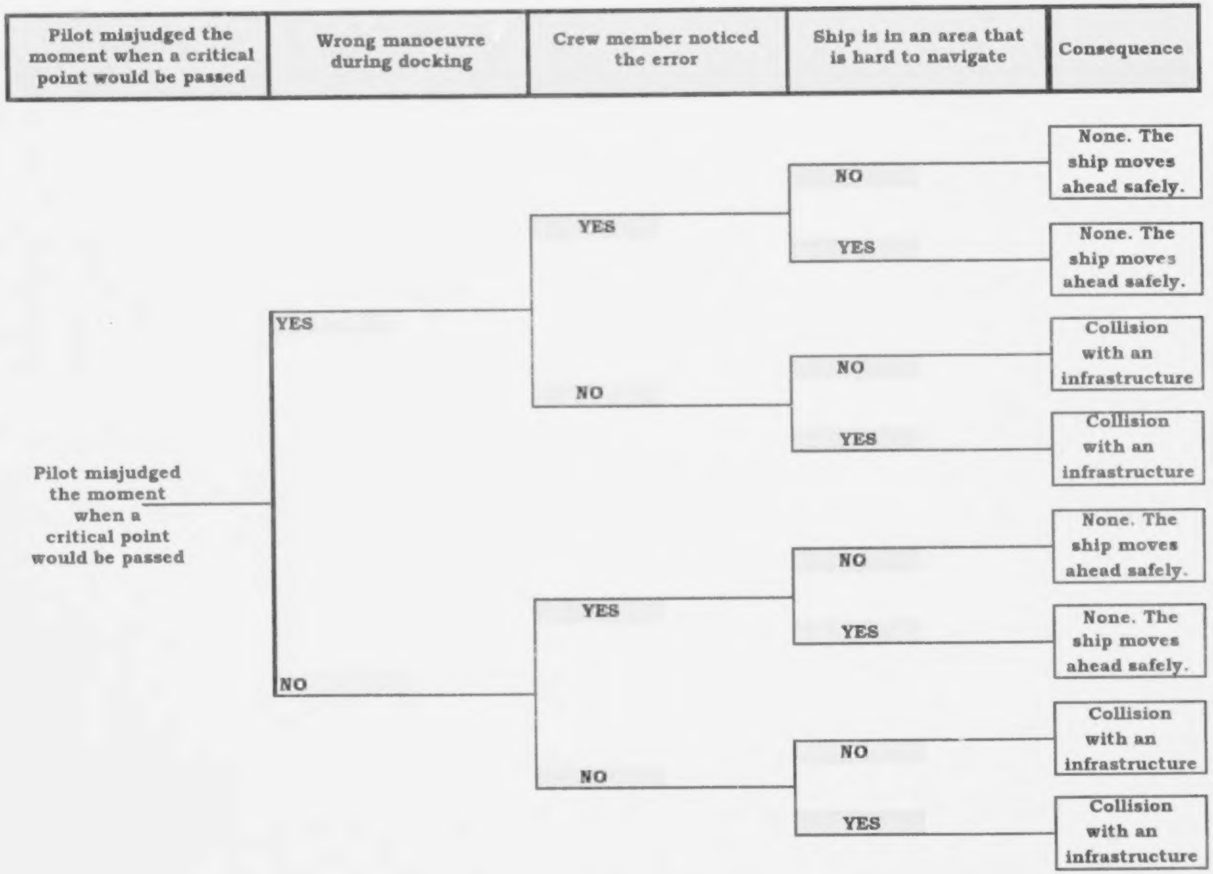
*Pilot errs in preparing the navigation plan*


Positioning error
Wrong manoeuvre ordered
Crew member noticed error
Ship is in an area that is hard to navigate
Consequence
Positioning error
YES
NO
YES
NO
YES
NO
NO
YES
NO
YES
NO
YES
NO
YES
None. The ship moves ahead safely.
None. The ship moves ahead safely.
Bottom contact
Grounding
None. The ship moves ahead safely.
None. The ship moves ahead safely.
Grounding
Collision with a ship

## *Pilot errs in preparing navigation plan*


Pilot misjudged navigating conditions
Pilot mistimed order to helsman
Crew member noticed error
Ship is in an area that is hard to navigate
Consequence
Pilot misjudged navigating conditions
YES
NO
YES
NO
YES
NO
NO
YES
NO
YES
NO
YES
NO
YES
None. The ship moves ahead safely.
None. The ship moves ahead safely.
Grounding
Grounding
None. The ship moves ahead safely.
None. The ship moves ahead safely.
Grounding
Grounding

## *Pilot errs in preparing navigation plan*


Pilot misjudged the moment when a critical point would be passed
Wrong manoeuvre during docking
Crew member noticed the error
Ship is in an area that is hard to navigate
Consequence
Pilot misjudged the moment when a critical point would be passed
YES
NO
YES
NO
YES
NO
NO
YES
NO
YES
NO
YES
NO
YES
None. The ship moves ahead safely.
None. The ship moves ahead safely.
Collision with an infrastructure
Collision with an infrastructure
None. The ship moves ahead safely.
None. The ship moves ahead safely.
Collision with an infrastructure
Collision with an infrastructure